Energy

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DOE/ID/12790-2
(DE91013559)

NEW INDUSTRIAL HEAT PUMP APPLICATIONS TO FRUCTOSE PRODUCTION

Phase I

Final Report

April 1990

Work Performed Under Contract No. FC07-88ID12790

For
U.S. Department of Energy
Office of Industrial Technologies
Washington, D.C.

By
Linnhoff March
Leesburg, Virginia

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Available to the public from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

Printed in the United States of America, Office of Scientific and Technical Information, Oak Ridge , Tennessee

DOE/ID/12790--2

DE91 013559

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Prepared for
U. S. Department of Energy
Idaho Operations Office, Idaho Falls, ID
Sponsored by the Office of the Assistant Secretary
for Conservation and Renewable Energy
Office of Industrial Technologies
Washington D.C.

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CONTENTS

EXECUTIVE SUMMARY

An energy cost reduction study of the American Fructose Decatur, Inc. High Fructose Corn Syrup (HFCS) manufacturing process (SIC Code 2046) has been completed. Of particular interest were the opportunities for utilizing heat pumps for energy cost reduction or other profit improving uses. Pinch Technology was used to identify heat recovery, heat pumping, process modification and cogeneration options. Pinch Technology provides a thermodynamically consistent base from which the relative merits of competing cost reduction options can be assessed.

The HFCS process consists of a milling step required to produce a starch slurry. The starch is then thinned by jet cooking and enzymatic action, converted to dextrose and finally isomerized to fructose. The process is characterized by large evaporation and drying loads and is energy intensive, as are other similar processes in the wet corn milling industry.

The overall study results are summarized in Table S-1. Substantial energy cost reduction possibilities exist. Improved heat recovery is the most attractive option with project paybacks in the range of 12-18 months being expected.

The use of heat pumps, in the form of mechanical vapor recompression (MVR) and thermocompression evaporators, is well established in the corn processing industry and this plant presently uses MVR's effectively. However, additional opportunities were identified which could result in significant savings. On an energy basis alone such projects may not be attractive, paybacks being in the 5 year range. However under the right circumstances combinations of modified evaporation sequences and additional heat pumping can offer a cost effective (energy plus capital) means of increasing plant throughput substantially (up to 30%) if the evaporation system is bottlenecked.

Cogeneration is another technology well established in the corn processing industry. The site under study did not incorporate a cogeneration facility, however several possible schemes were identified. Despite the savings potential, up to $1.6 million/year, paybacks in the range of 4-5 years were encountered for the bigger schemes identified due mainly to the relatively low cost of power. However, a small scheme utilizing a steam turbine could save $157,000/year at a payback of 24 months.

It is felt that the results obtained in this study are applicable to other wet corn milling sites which include a refinery section, due to the similarity of processes throughout the industry. This study and others indicate that reductions in thermal energy consumption of 15-25% can be expected through increased heat recovery. Also, the use of MVR and thermocompression evaporators is appropriate and additional economically viable opportunities exist for using industrial heat pumps to increase even further the level of energy cost reduction achievable.

Table S-1
Savings Identified $/Yr

Project	Refinery	Mill	Total
Additional Heat Recovery	442,500	395,000	837,500
Process Modification/ Heat Pumping	329,000	82,000	409,000
Cogeneration	-	-	157,000 to 1,600,000

1.0 INTRODUCTION

An energy cost reduction study of the American Fructose Decatur, Inc. High Fructose Corn Syrup process has been completed. This process is classified under SIC Code 2046. The objective was to find cost effective energy cost reduction projects and to develop a coherent strategy for realizing the savings. There are many possible options for reducing energy cost, these are shown in Figure 1. To facilitate a fair comparison of the options, Pinch Technology was used to identify appropriate heat recovery, heat pumping and cogeneration options.

Of particular interest were the opportunities for utilizing heat pumps, for energy cost reduction or other profit increasing uses. Therefore, where a heat pumping scheme was identified, its merits relative to other potential projects was carefully evaluated to ensure that the heat pump was technically and economically sound.

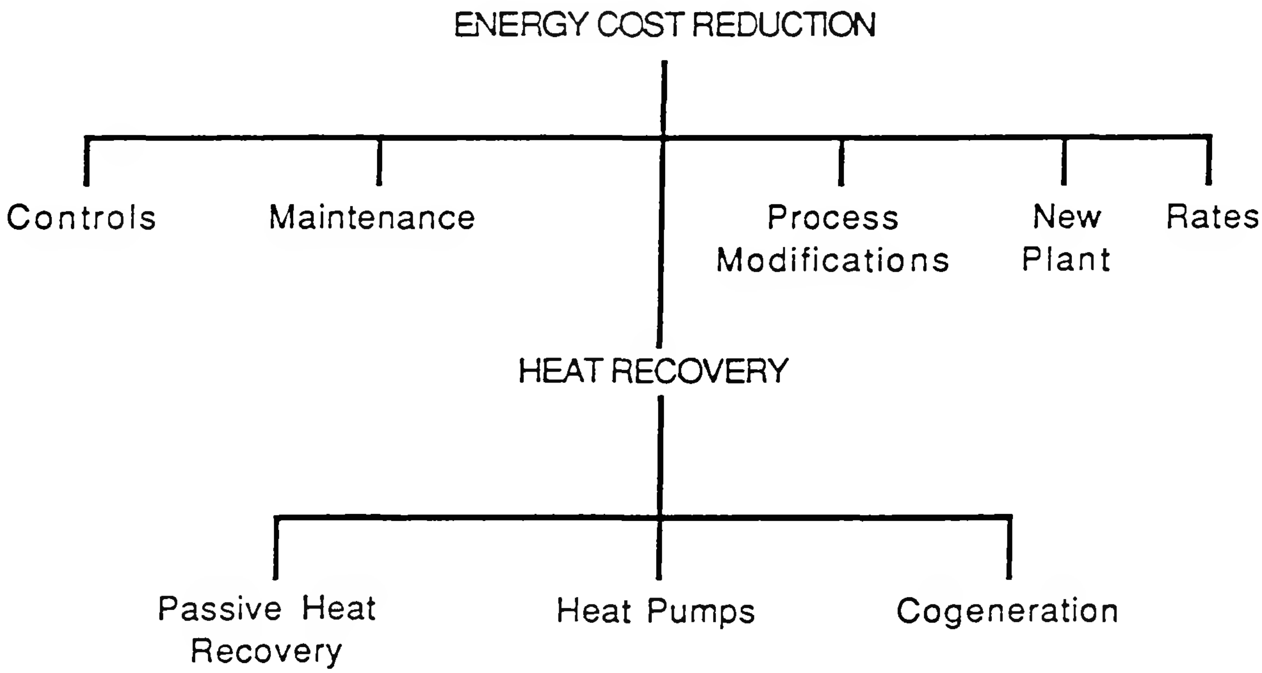


Figure 1 Energy Cost Reduction Options

2.0 THE DECATUR PLANT

American Fructose Decatur, Inc. is part of the American Maize - Products Company, a major corn processor. The company also has manufacturing plants at Dimmit, Texas and Hammond, Indiana.

The Decatur Plant manufactures high fructose corn syrup and associated byproducts. The energy bill of about $8.50 million is split between coal, gas, and electricity; electricity accounting for about $4.8 million. Because of the choice of coal as the primary fuel, the site enjoys a low marginal steam cost, and has negotiated an attractive electrical rate with the local utility. Almost all of the site energy consumption is associated with product manufacturing and therefore the study addressed all the manufacturing operations.

The process consists of two quite distinct operations - milling of the corn to obtain a starch slurry in the mill and conversion of starch to HFCS in the refinery. Figure 2 is a schematic of the mill operations.

The corn is first cleaned to remove dust, stones, broken grains, etc. The cleaning process consists of a rough cleaning followed by fine cleaning.

The cleaned corn is steeped or soaked for 24 to 48 hours in the steeping tanks. Steeping softens the kernel, disintegrates the starch-binding protein in the kernel, and removes solubles for recovery. Steeping is completed in a series of tanks with a countercurrent flow of steepwater. The steepwater that is drained from the last tank is concentrated in evaporators and can eventually be used in animal feed.

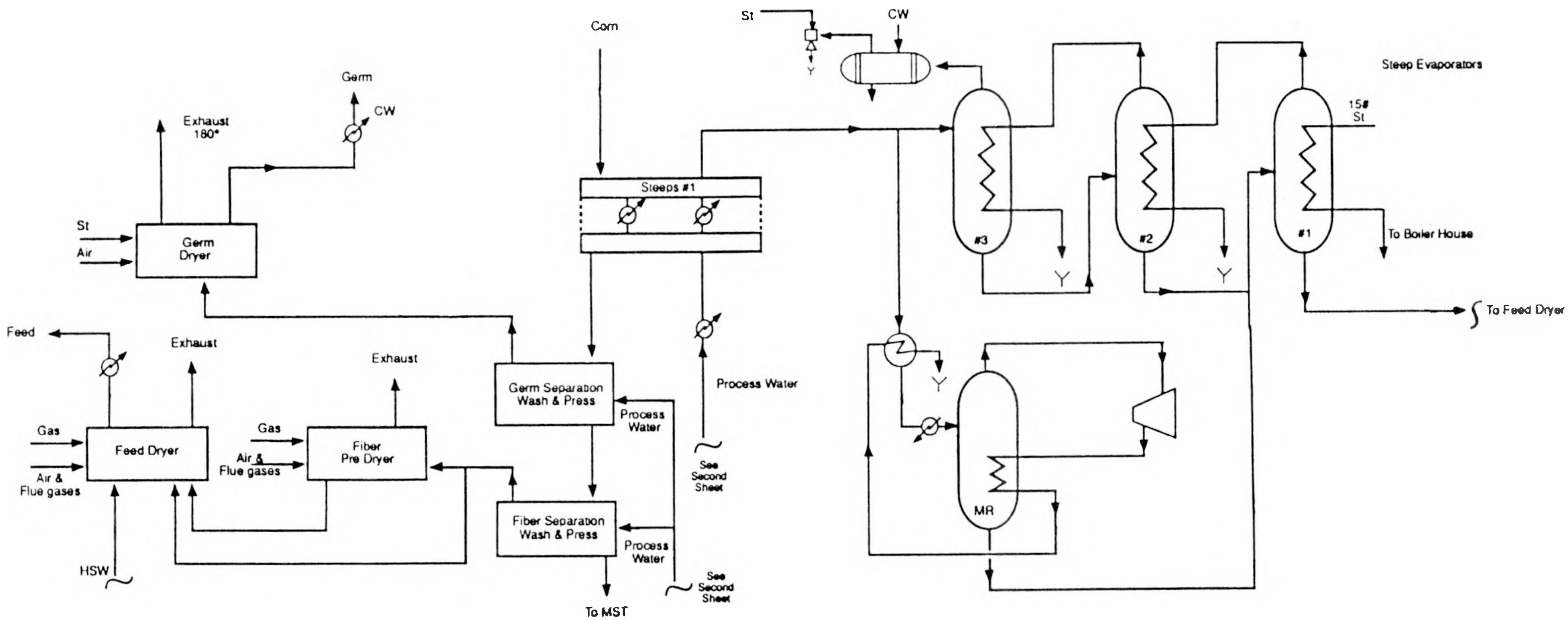


Figure 2 Mill process schematic 1 of 2

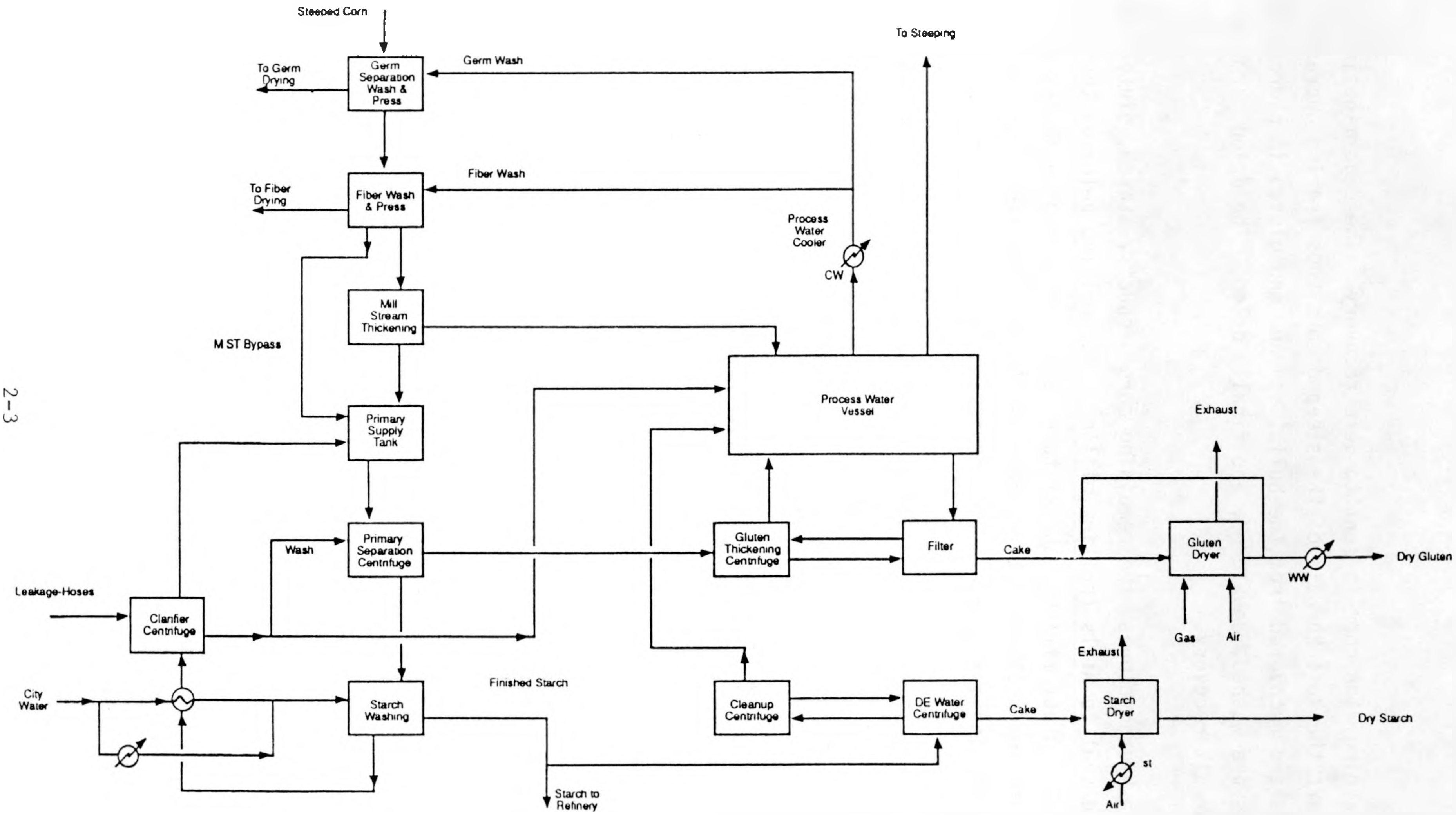


Figure 2 Mill process schematic 2 of 2

After steeping, the corn is sent to germ recovery. The degerminating mill tears apart the soft kernels of the steeped corn thus freeing uncrushed germs. The germs are recovered from the hulls, starch, and gluten in hydrocyclones. The germs are washed, dewatered, and finally dried. The dried germs are then ready for oil recovery.

After the hydrocyclones, the remaining corn products, starch, gluten, and hulls are sent to mills for fine milling. The milling releases the rest of the starch. After milling, the mixture is passed through a series of screens to separate the hulls or fibers from the starch. The fibers are washed to recover additional starch and then dewatered and dried for animal feed.

The starch and gluten slurry or starch milk that is produced in the hull washing step is ready to be separated into individual components. The starch milk goes through several stages of separation. The first separation is done in a centrifuge, and the remainder are done in hydrocyclones. The separated gluten is dewatered first by floatation, then by centrifugation and is finally processed through dryers. After the gluten has been separated, some of the starch milk is dewatered and dried to the final corn starch product. The other portion of the starch milk is sent to the high fructose corn syrup refinery.

The refinery process shown in Figure 3 begins by thinning the starch. The slurry first passes through the jet cookers. Steam is used to inject the starch slurry into the cooker. After the jet cookers, the starch slurry passes through a set of thinning coils and into a flash chamber. After the flash chamber, the slurry is transferred to the enzyme liquefaction reactor to continue thinning the starch and is finally flashed again to the desired temperature.

The thinned starch slurry is transferred to a series of saccharification reactors. Once the desired dextrose level is reached, the corn syrup is filtered and sent through ion exchange columns. After ion exchange, the corn syrup is concentrated to about 45% solids in an evaporator.

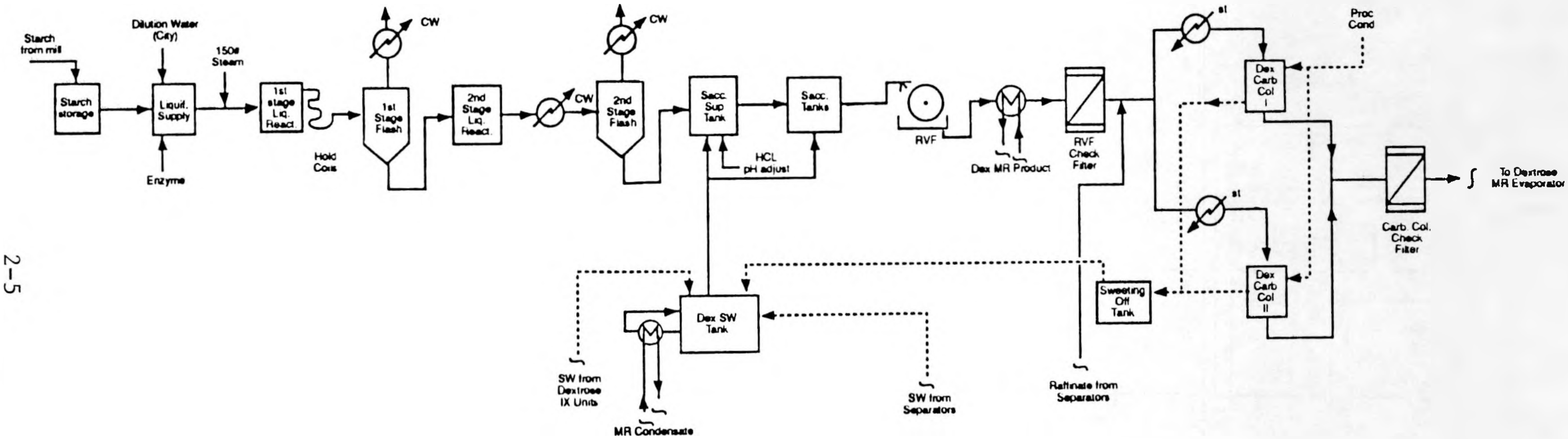


Figure 3 Refinery process schematic 1 of 3

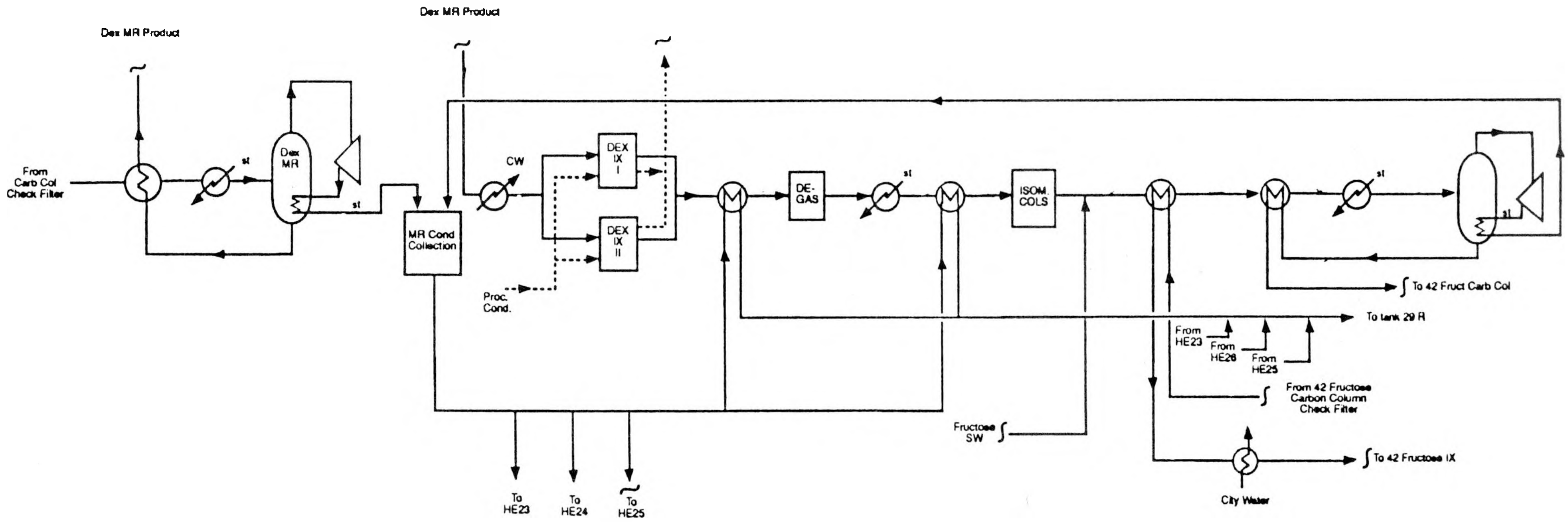


Figure 3 Refinery process schematic 2 of 3

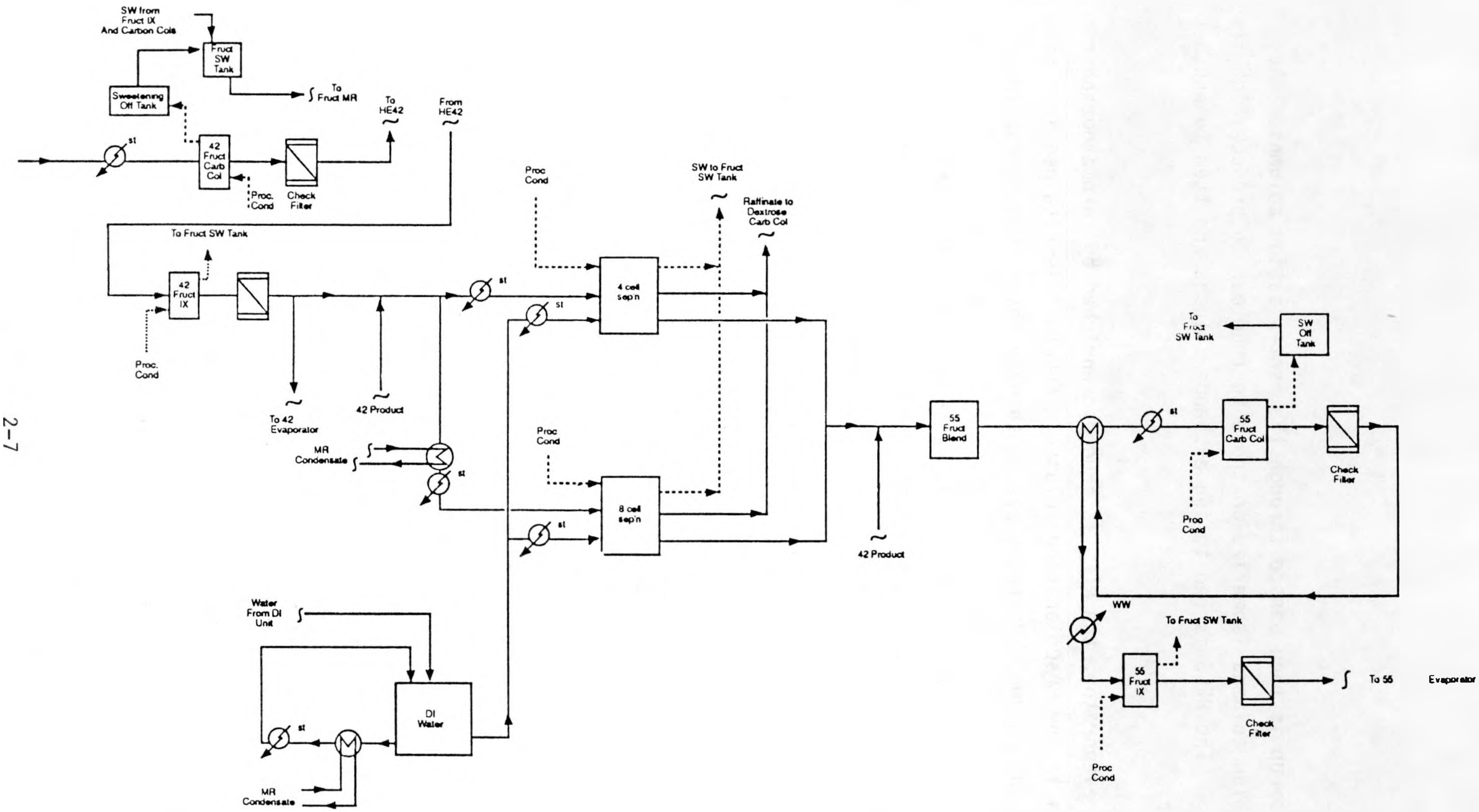


Figure 3 Refinery process schematic 3 of 3

The corn syrup is then passed through the isomerization columns. The isomerization columns isomerize dextrose to fructose to produce high fructose corn syrup. The HFCS is fed to ion exchange columns and then to another evaporator.

After the evaporator, the HFCS is fructose enriched by chromatographic separation in the fractionation columns. Fructose is retained in a greater degree in the column. Dextrose passes through the column as raffinate.

The HFCS is washed out of the fractionation columns with water. The final products are blended and then concentrated to about 77% solids in the final evaporators.

The majority of the process energy consumption is accounted for by:

- Evaporation of steepwater
- Drying of the various mill byproducts
- Jet cooking of the starch slurry
- Evaporation of dextrose, intermediate fructose and the final HFCS products

Due to the energy intensive nature of the process, American Fructose has already implemented many energy cost reduction measures including:

- heat recovery from hot process and condensate streams.
- use of mechanical vapor recompression MVR evaporators instead of multi effect units.
- heat recovery from boiler flue gases.

The wet corn milling industry is a large consumer of energy in the U.S. In 1981, industry expenditures of purchased fuels and electrical energy amounted to $275.3 million a 10% increase over 1980.

The major products from the wet corn milling process include corn oil, assorted feed products, dry starches/modified starches and regular and high fructose corn syrups. Despite this range of products, the same basic processing steps are common throughout the industry. The energy intensive grinding, evaporation and drying steps mean that high energy demand is also a common requirement throughout the industry.

The HFCS industry has seen quite rapid growth over the past 10 years, driven mainly by the use of HFCS to replace sugar as the sweetener in soft drinks. The growth of the industry is favored by the availability of starch based feed stocks in many countries, sugar price controls in some countries and the likelihood of a worldwide rise in sugar prices. There is therefore a good possibility of long term expansion in HFCS production.

3.0 ADDITIONAL HEAT EXCHANGE BETWEEN PROCESS STREAMS

Minimum energy consumption targets for the existing process were determined using a pinch technology analysis. Due to operability considerations, heat integration between the refinery and mill operations was not considered practical.

Based on an existing process energy consumption of 1000 units, the scope for improved heat recovery is shown in Table 3.1. The energy targets are also shown on the grand composite curves for the refinery and mill shown in Figures 4a and 4b. The existing heating utility, Q_H, has been normalized to 1000 'heat units' to respect the proprietary rights of American Fructose. Of the existing 645 units consumed in the refinery, 430 are supplied by an existing heat pump (the refinery MVR evaporator) and 215 units by steam. Similarly, in the mill 133 units of the existing 355 unit consumption are supplied by an existing heat pump (the mill MVR evaporator) and 222 by steam and fuel gas.

It is important to note that the grand composite curve is a profile of the process heating and cooling demands. Its construction inherently allows for the maximum possible level of heat exchange between process streams. Therefore, the utility demands illustrated on the curves are the minimum thermodynamically practical (i.e. utility targets).

Table 3.1 Actual vs. Target Energy Consumption

	Refinery	Mill	Total
Existing Consumption	645	355	1,000
Target Consumption	567	282	849
Target Savings Units	78	73	151
Target Saving	12%	20%	15%

Note that the percentage savings in Table 3-1 refer to the <u>total</u> heat supplied to the process, and would be much greater if referred to the heat supplied by steam/fuel only. For example, the 78 units of target savings in the refinery represent 36% savings in the heat supplied by steam.

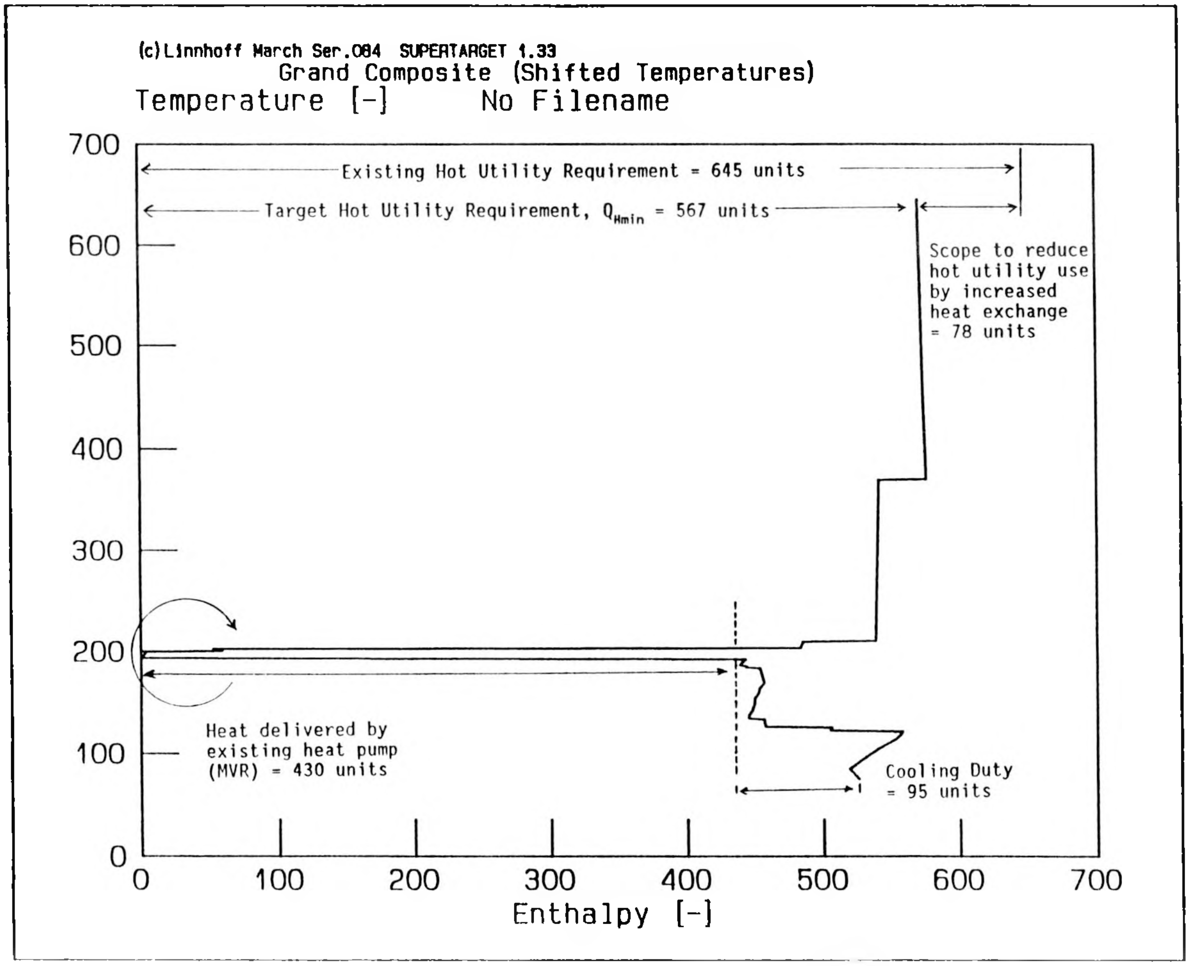


Figure 4a Base Case Refinery Grand Composite Curve

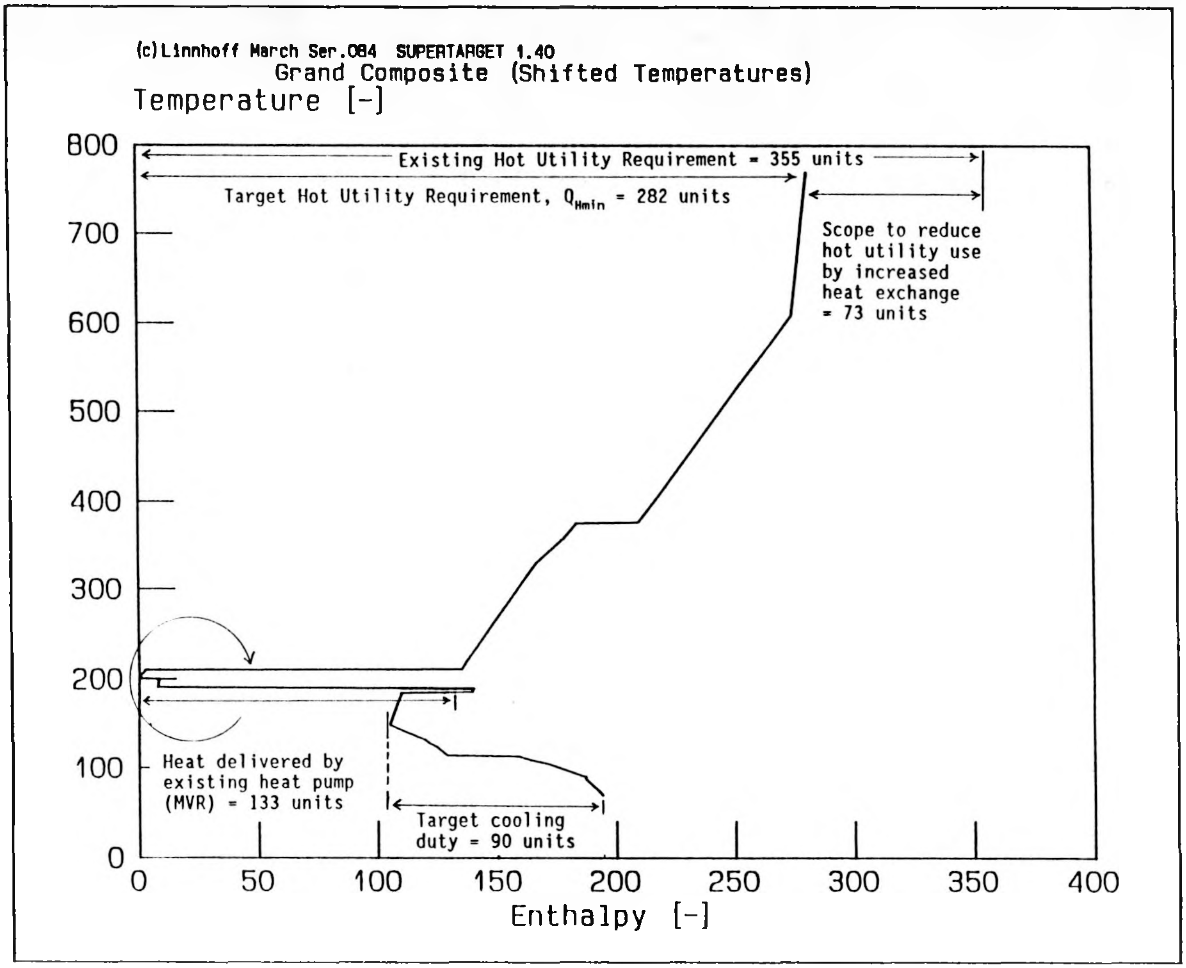


Figure 4b Base Case Mill Grand Composite Curve

Following the initial targeting exercise, the heat recovery projects required to get from the existing energy consumption to the target consumption were identified. This exercise resulted in a package of 10 refinery projects and 6 mill projects being identified.

The refinery heat recovery project savings total $442,500/year achieving 76% of the targeted savings shown in Table 3-1. The projects identified are summarized in Table 3.2. The total installed cost of the projects is estimated at $450,000 resulting in a simple payback of 13 months, with the payback of individual projects ranging from 7 to 26 months.

The mill heat recovery projects savings total $300,000/year achieving 77% of the targeted savings shown in Table 3-1. In addition, boiler feed water heating can save $95,000/year. The projects identified are summarized in Table 3-3. The total estimated installed cost of the projects is $606,000 resulting in a simple payback of 18 months, with the payback of individual projects ranging from 11 to 38 months.

Table 3.2. Refinery Heat Recovery Projects (Project 3.0R)

Project No.	Description
1	Preheat Starch Slurry to Liquefication
2	Preheat Dextrose/Raffinate to Carbon Columns
3	Increased Preheat of Dextrose to MVR Evaporator
4	Increased Preheat of Fructose to MVR Evaporator
5	Preheat of Fructose to Final Evaporation
6	Preheat of Dextrose to Isomerization
7	Preheat of Syrup to Separators
8	Preheat of Water to Separators
9	Use of High Temperature Flue Gases
10	City Water Heating

Table 3-3. Mill Heat Recovery Projects (Project 3.0M)

1	City Water Heating
2	Starch Drier Air Heating
3	Gluten Drier Air Heating
4	Integration Between Steep Water Evaporators
5	Boiler Feed Water Heating
6	Modifications to Drier Controls

4.0 HEAT PUMPING OPPORTUNITIES

The grand composite curves for both the mill and refinery, without the present heat pumps incorporated, exhibit a long thin 'nose' at the pinch as illustrated in Figures 4a and 4b. This nose represents a requirement for heat at a relatively low temperature above a heat source and is indicative of a good heat pump opportunity. This has already been recognized by American Fructose and the existing plant has two MVR evaporators one in the refinery and one in the mill. The effect of the existing refinery heat pump is shown schematically in Figure 5a. In this case, all the heat is being pumped correctly from below to above the pinch. The target after heat pumping 430 units is 137 units, thus the total heat supplied is 567 units, the original target. Figure 5b shows the effect of the existing mill heat pump. In this case, some of the heat pumping is ineffective and is not resulting in savings. The target after heat pumping 133 units is 170 units representing a total heat supply of 303 units. This is 21 units higher than the target heat supply meaning that 21 units of heat pumping are 'inappropriately placed' and that the power supplied to pump the 21 units could be saved by rearranging the mill heat exchange configuration.

The use of heat pumps results in savings additional to those obtained by increased heat exchange between process streams. Therefore, the benefits of additional heat pumping opportunities are evaluated relative to the base case grand composite curves in Figures 4a and 4b and the upper illustration in Figure 9a. Despite the existing MVR's, other heat pumping opportunities exist.

4.1 Refinery Heat Pumping

Several projects involving additional heat pumping exist. These are:

- 4.1R) Use a thermocompressor to reduce the size of the present MVR.
- 4.2R) Convert the existing evaporators to single effect MVR units.
- 4.3R) Convert the existing evaporators to operate with thermocompressors round the first effect.

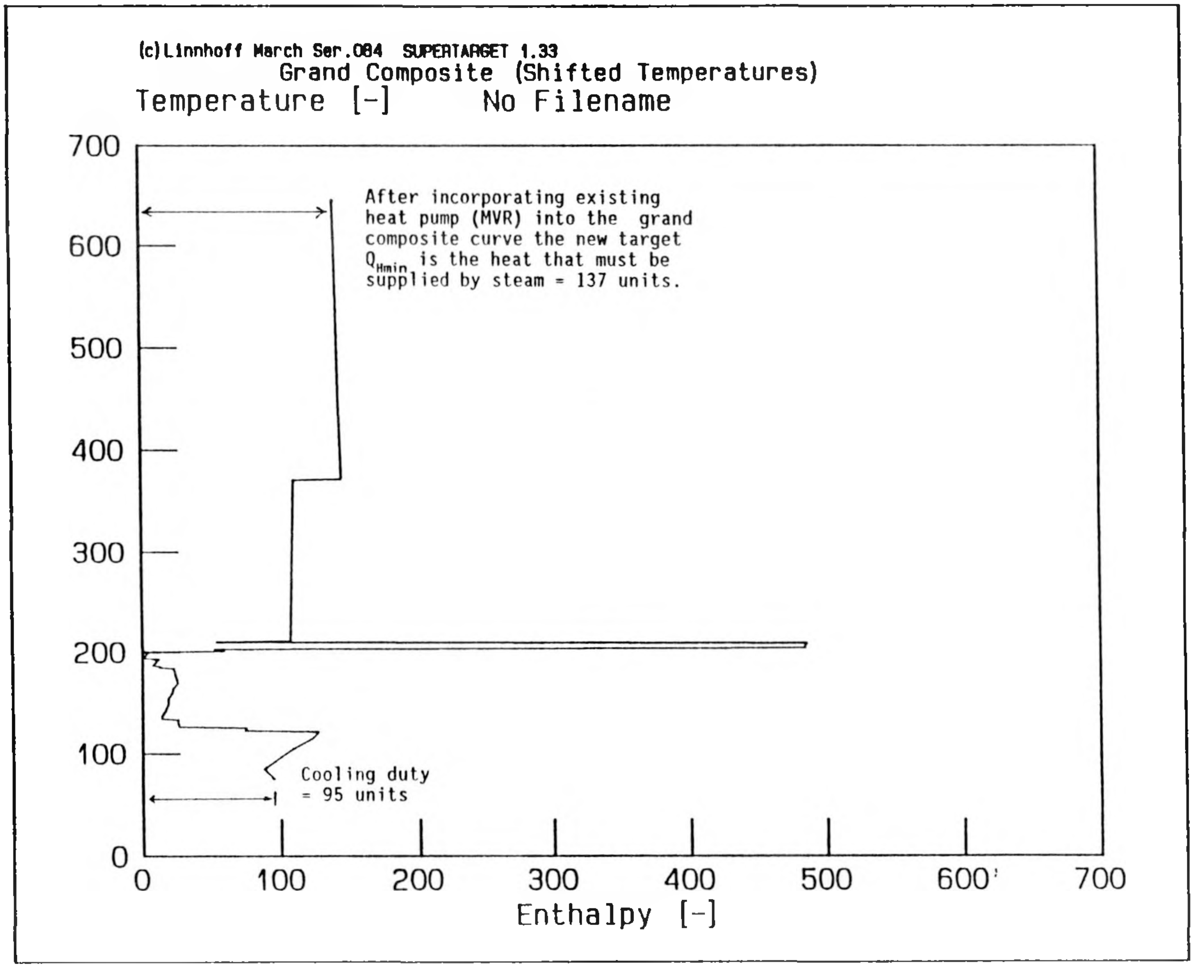


Figure 5a Grand Composite Curve for Refinery Incorporating Existing Heat Pump (MVR)

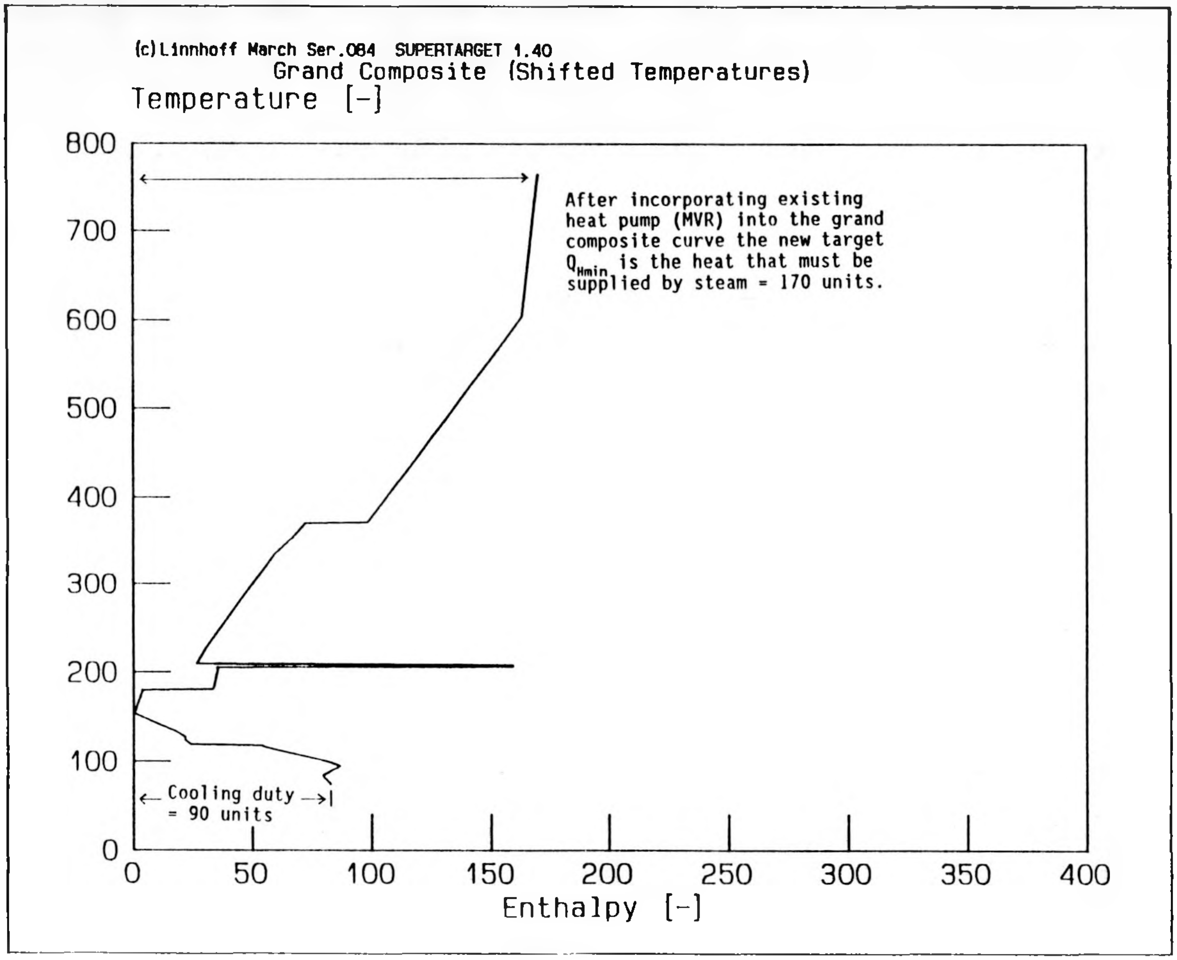


Figure 5b Grand Composite Curve for Mill Incorporating Existing Heat Pump (MVR)

Each of these is addressed below:

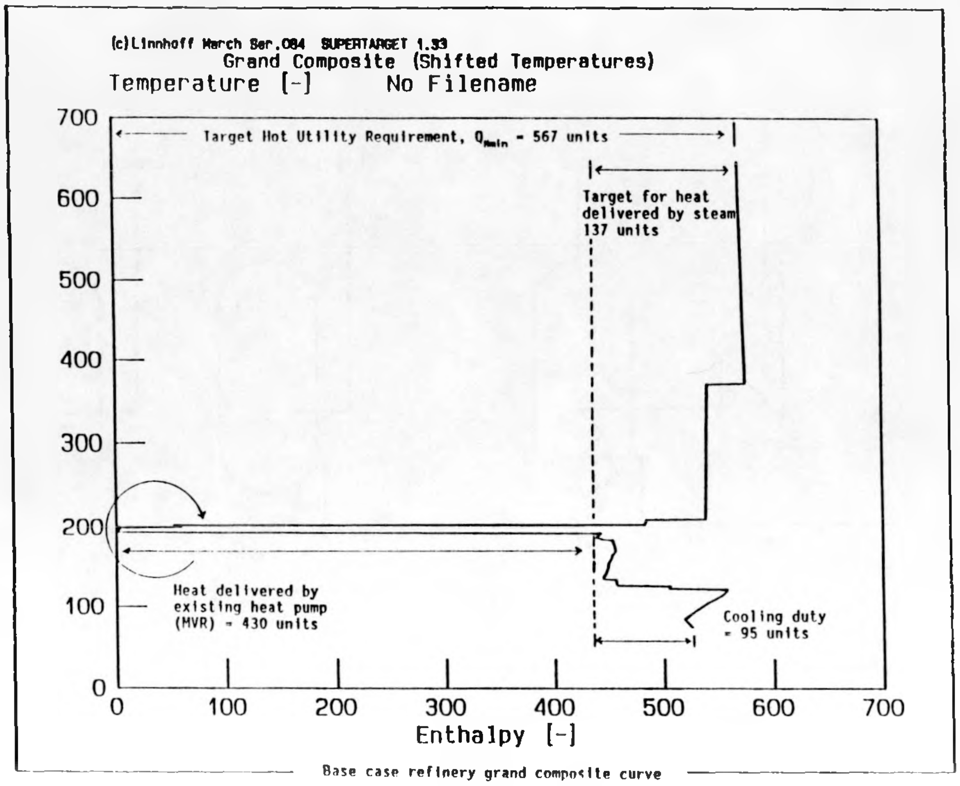
4.1.1 Use of thermocompressor (Project 4.1R). Scope exists to use thermocompressor to pump heat now being pumped by the MVR. The existing MVR delivers 430 units of heat, meaning that 137 units of steam are required to satisfy the target of 567 units. Currently steam is let down from HP to LP through an expansion valve to a level suitable for the duty. Figure 6a shows that by letting the steam down through a thermocompressor, 106 units of heat can be pumped around the pinch. This leaves only 324 units to be supplied by the MVR. This scheme does not save steam (the HP steam demand remains at 137 units), but reduces the amount of vapor that is compressed in the MVR resulting in power savings.

Figure 6b shows a flow sheet for this scheme. The vapor load on the compressor can be reduced resulting in potential power savings worth $102,000/yr. The actual savings will depend on the performance of the thermocompressor and the operating pressures of the evaporators.

4.1.2 Converting Multi Effect Evaporators to Single Effect MVR Units (Project 4.2R). Modifying the entire multi effect evaporation duties to occur at the same temperature at which the existing MVR unit operates results in the grand composite curve shown in Figure 7. The extended nose compared to the base line case indicates the additional heat pumping opportunity. In fact, the process heating load Q_H is increased by this modification, but because the MVR's effectively deliver very inexpensive heat, potential savings over the existing operation are $381,000/yr.

These savings assume that the final solids content for both cases could be reached in the MVR. In practice the required 71-77 solids content may not be achievable and a finishing effect would be required. The savings indicated are therefore the maximum that could be expected.

Retrofitting of multiple effect units as MVRs is feasible. However, substantial additional surface area is required in addition to a compressor and repiping.



Base case refinery grand composite curve

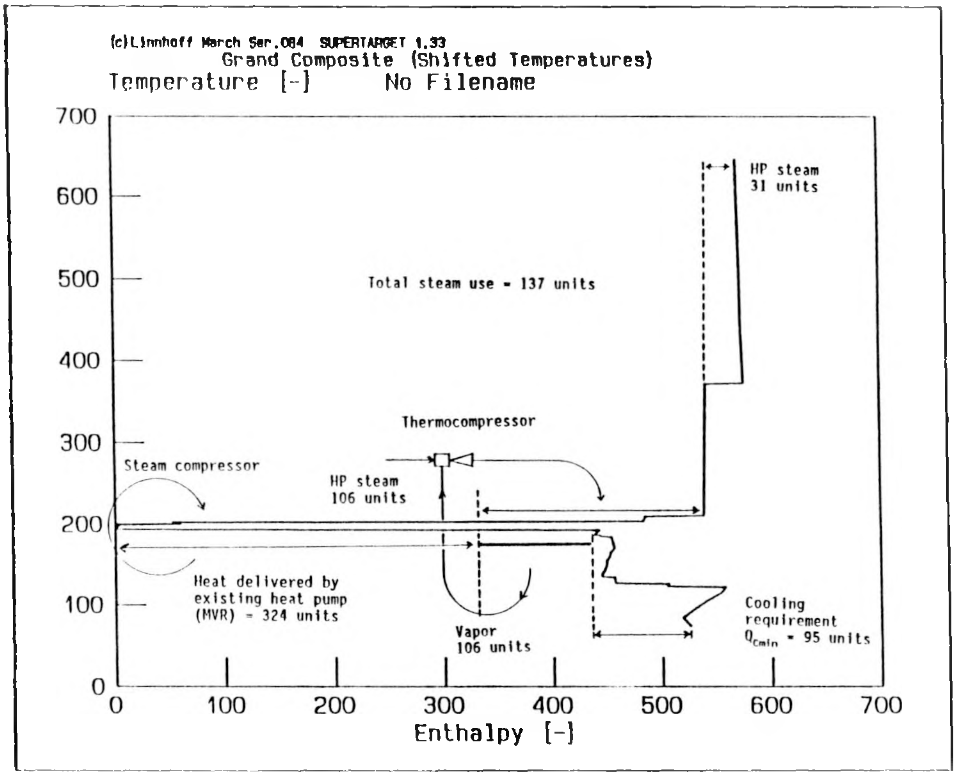
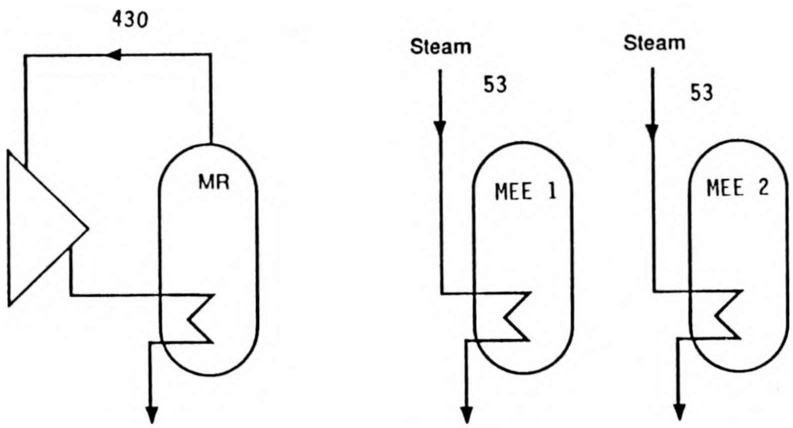


Figure 6a Expanding steam through a thermocompressor allows 106 units of heat to be pumped round the pinch. Note that the total steam use remains at 137 units, but that heat supplied by the MVR falls to 324 units.

Existing Situation



After Modification

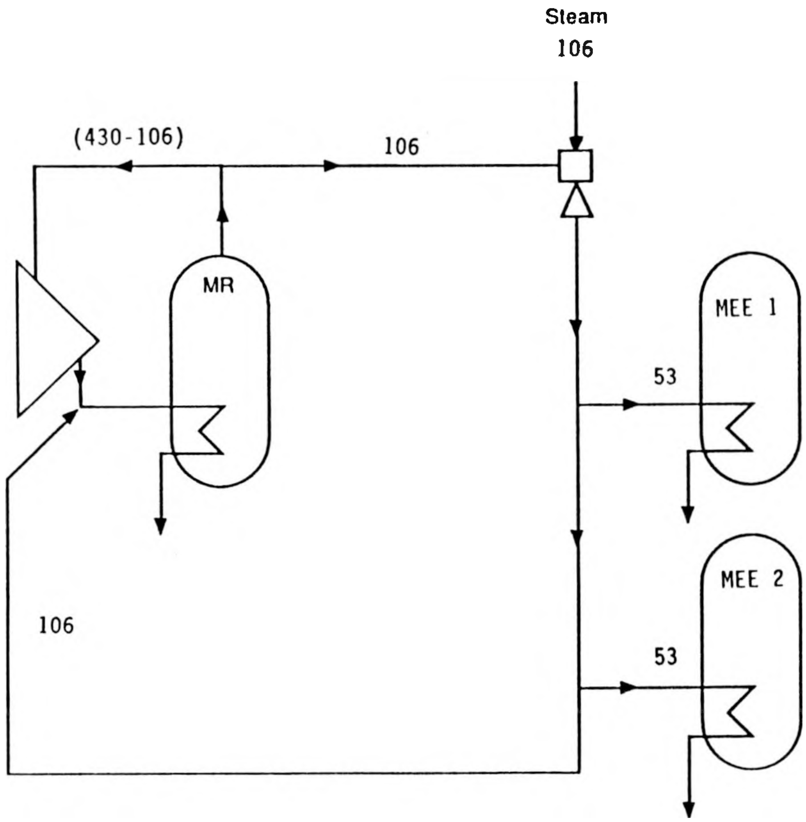
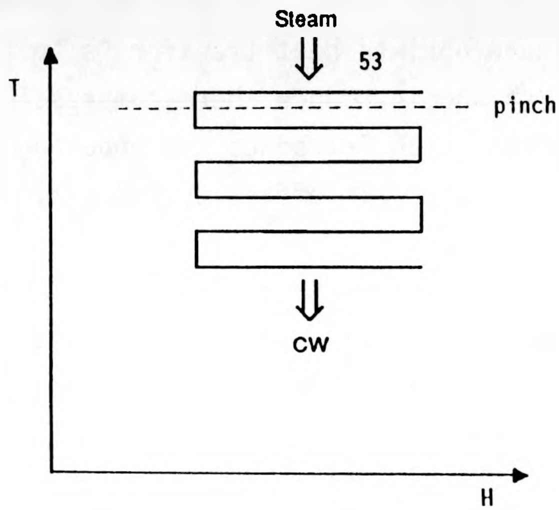


Figure 6b Equipment configuration suggested by Figure 6a

Existing Situation



After Modification

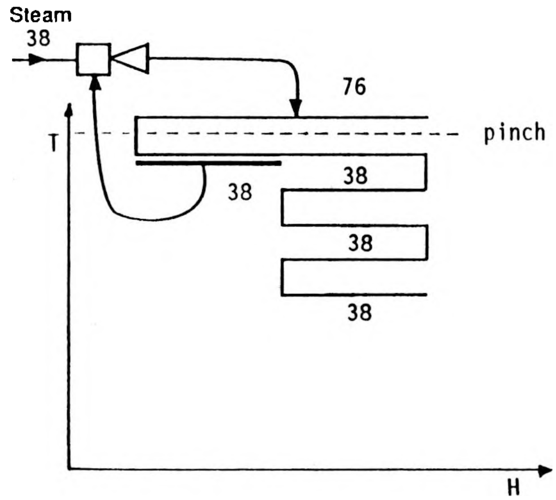


Figure 7 Effect of shifting loads within the evaporator

The estimated installed cost for this project is $1.7MM, resulting in a payback of 4.5 years.

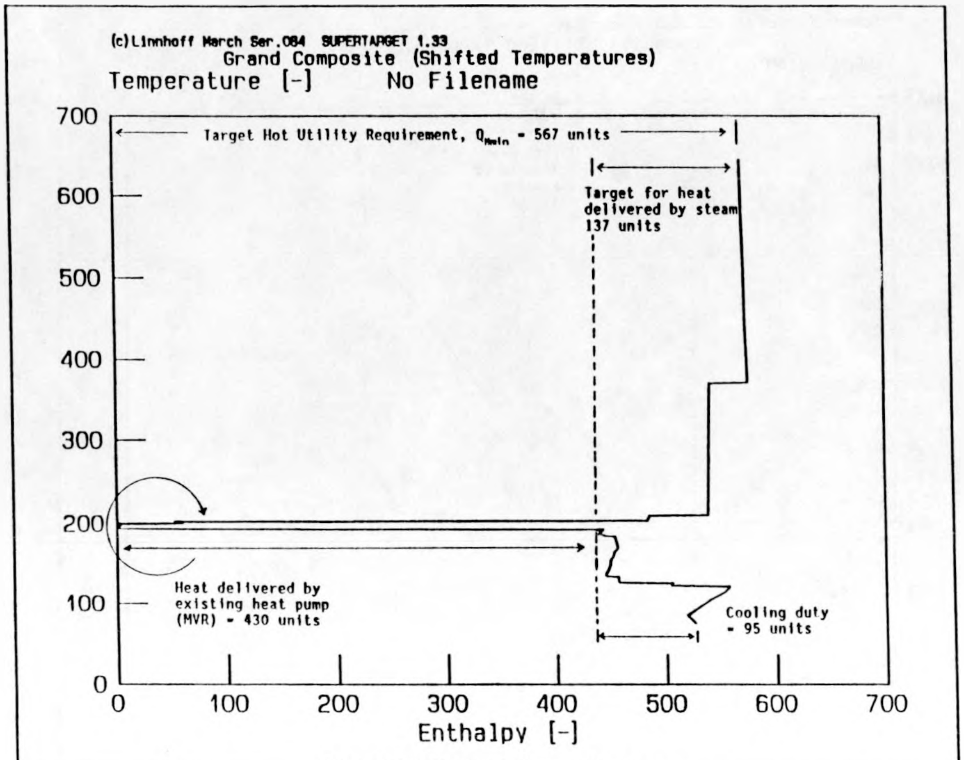
4.1.3 <u>Modify Multi Effect Evaporators to Include Thermocompression (Project 4.3R).</u> The multi effect evaporators in use take heat in above the pinch and reject it below the pinch, and therefore are not 'appropriately placed'. One way to reduce the amount of inappropriate heat transfer is to adjust the distribution of duties across each effect and introduce thermocompression. Figure 8 shows schematically how load shifting can introduce the opportunity for use of thermocompression for a typical triple effect evaporator.

Potential steam savings resulting from this scheme are $189,000/yr. The final savings are again dependant on the thermocompressor performance. The estimated installed cost of the project is $510,000, resulting in a payback of 2.7 years.

Implementation of this project would require additional surface for the first effects of the multi effect evaporators. The result of this is to reduce the loads on the remaining effects. By sizing the additional area appropriately this project could allow the dual objectives of energy saving and debottlenecking to be met cost effectively.

4.2 Mill Heat Pumping (Project 4.1M)

The major opportunity for heat pumping lies in the use of a thermocompressor to pump some of the heat now being pumped around the 'nose' with the existing MVR. Although no steam savings result, the power input to the MVR compressor is reduced as shown in Figure 9a, producing savings of $37,000 /yr. Figure 9b shows the corresponding flowsheet. This project is similar to that proposed for the refinery in Section 4.1.1.



Base case refinery grand composite curve

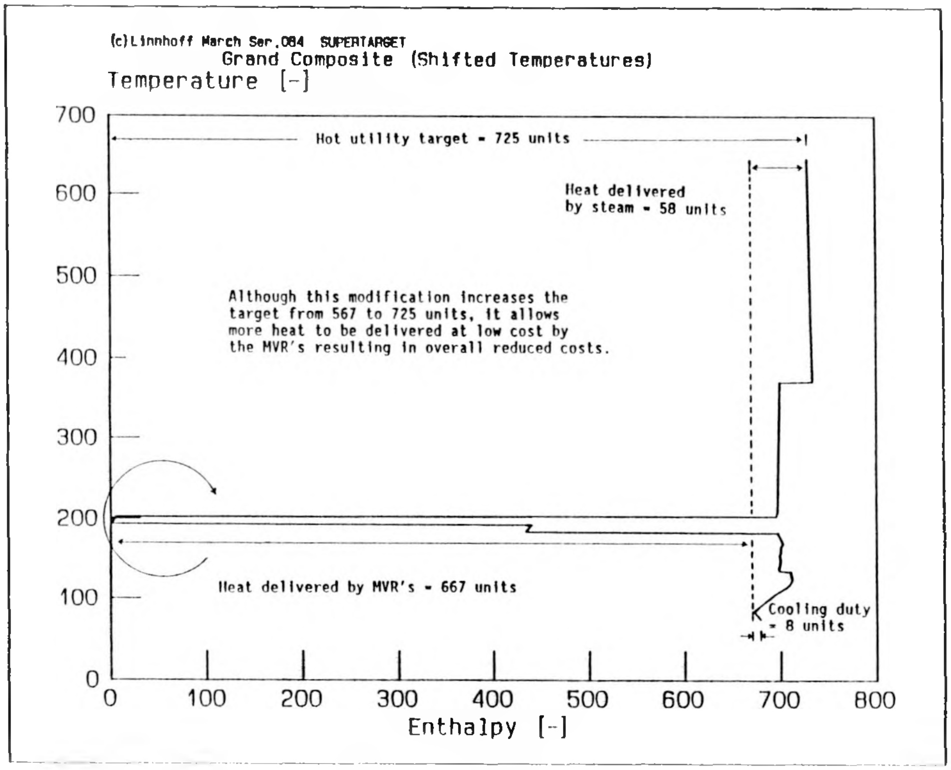
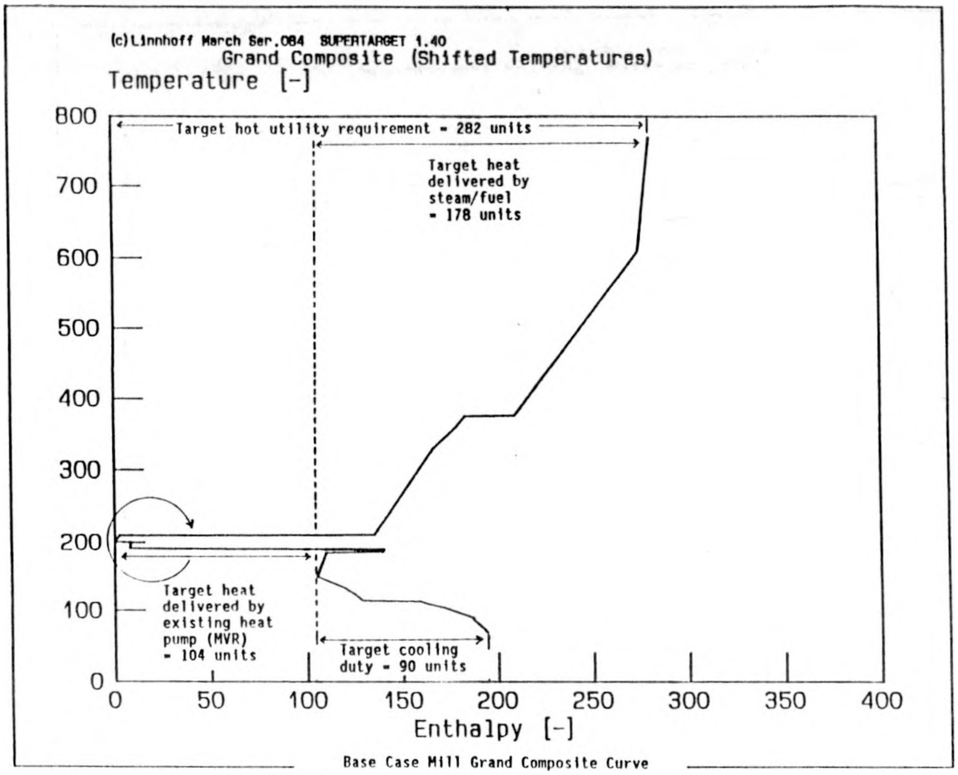


Figure 8 Grand composite curve showing effect of changing multi effect evaporators to MVR's



Base Case Mill Grand Composite Curve

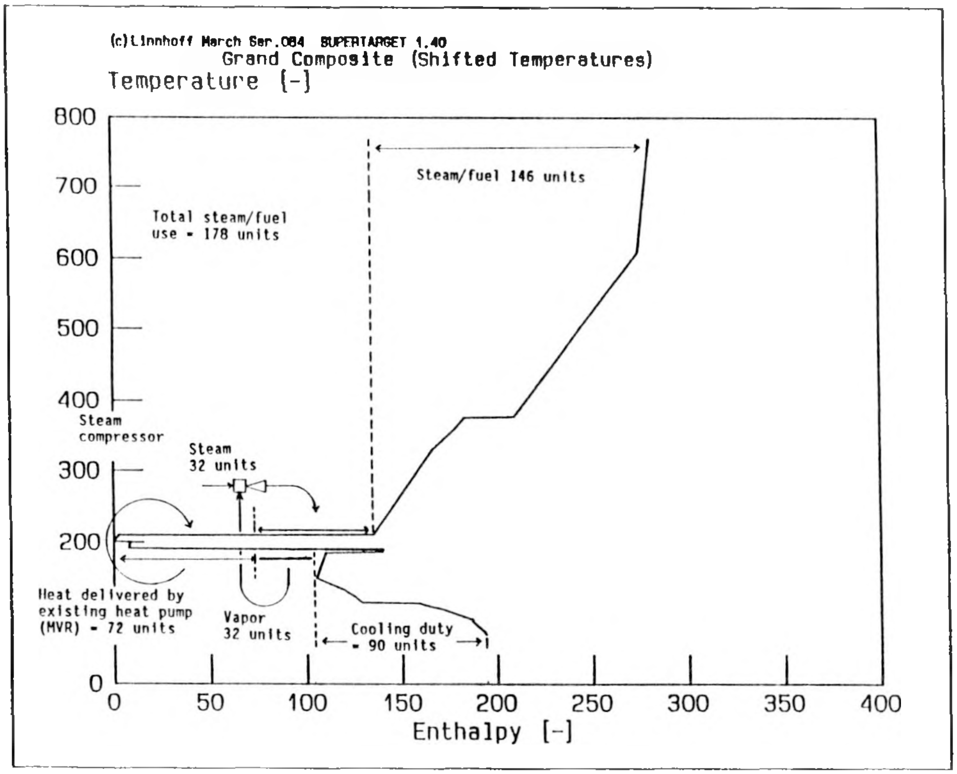
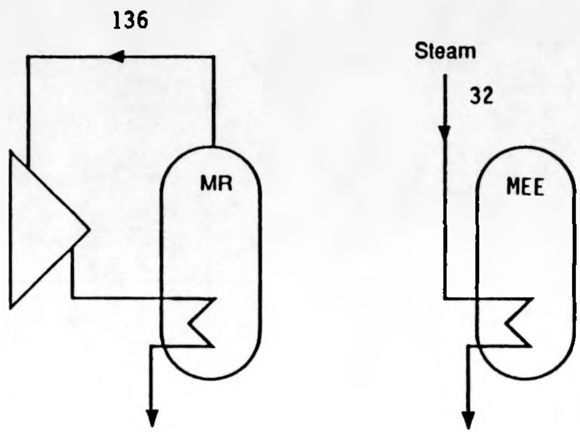


Figure 9a Expanding steam through a thermocompressor allows 32 units of heat to be pumped round the pinch. Note that the total steam/fuel use remains at 178 units, but that heat supplied by the MVR falls to 72 units.

Existing Situation



After Modification

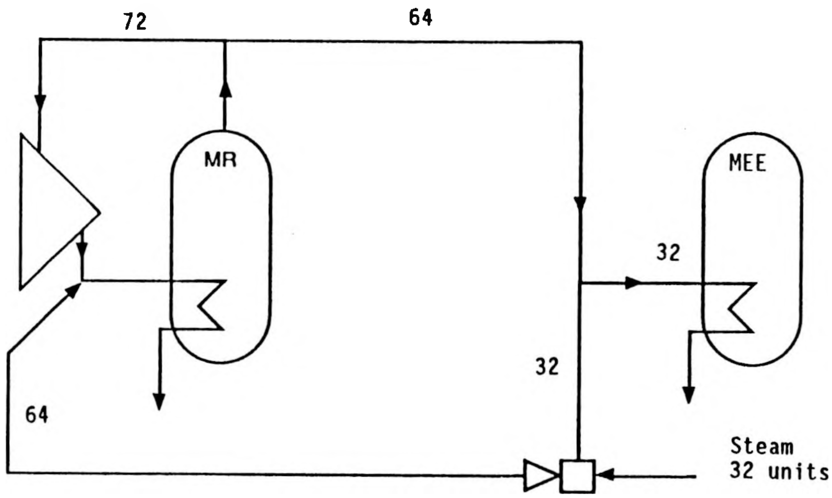


Figure 9b Equipment Configuration Suggested by Figure 9a

5.0 PROCESS MODIFICATIONS

A pinch analysis can help to identify some changes to the process operating conditions (i.e. pressure temperatures, flows, etc.) which result in reduction in energy usage. A number of these opportunities were identified in the refinery and mill.

5.1 Refinery Process Modifications

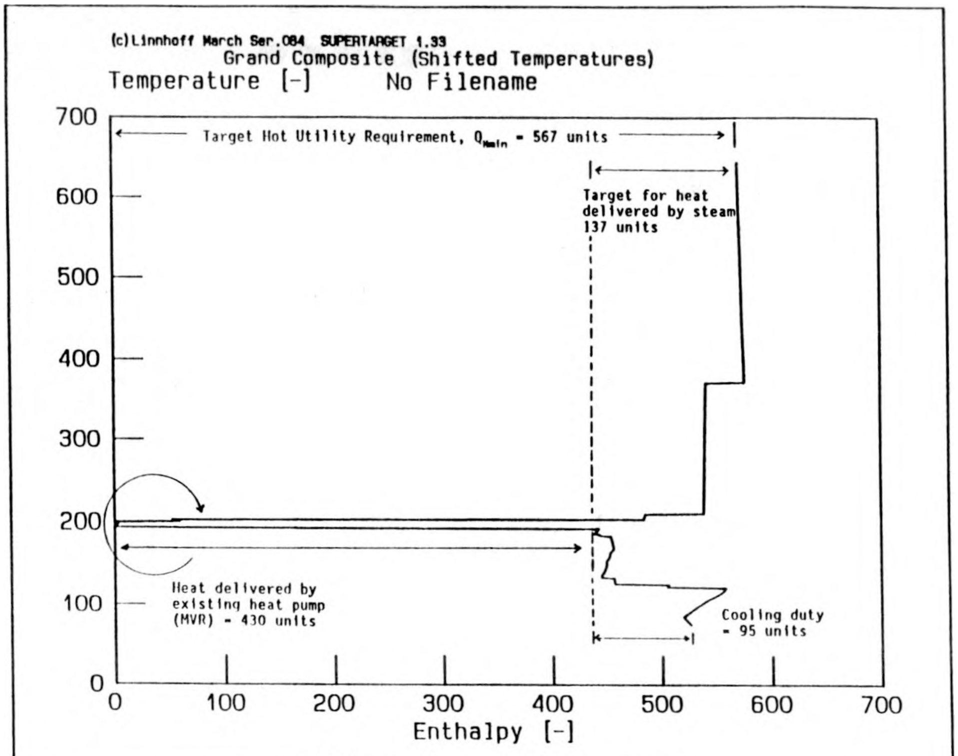
Several possibilities for such process modifications exist:

- 5.1R) Reduce the operating pressure of the multi effect evaporator first effects so that they operate entirely below the pinch.
- 5.2R) Introduce a dextrose (or fructose) pre-evaporator which operates either entirely above or entirely below the pinch.
- 5.3R) Add another effect to the multi effect evaporators.
- 5.4R) Operate the process at higher solids content.

Each of these is discussed below.

5.1.1 Reduced first effect pressures.(Project 5.1R)

Figure 10a shows the Grand Composite Curve for the refinery when the operating pressures of the multi effect evaporator first effects are reduced from their current levels to operate below the pinch. This reduces the amount of heat pumping required. The overall effect of the process modification is therefore to reduce the heat load that needs to be supplied by the existing MVR evaporator. This translates into a horsepower saving in the compressor rather than a steam saving and is worth $106,000/year. Figure 10b shows how the evaporation system looks before and after the modification.



Base case refinery grand composite curve

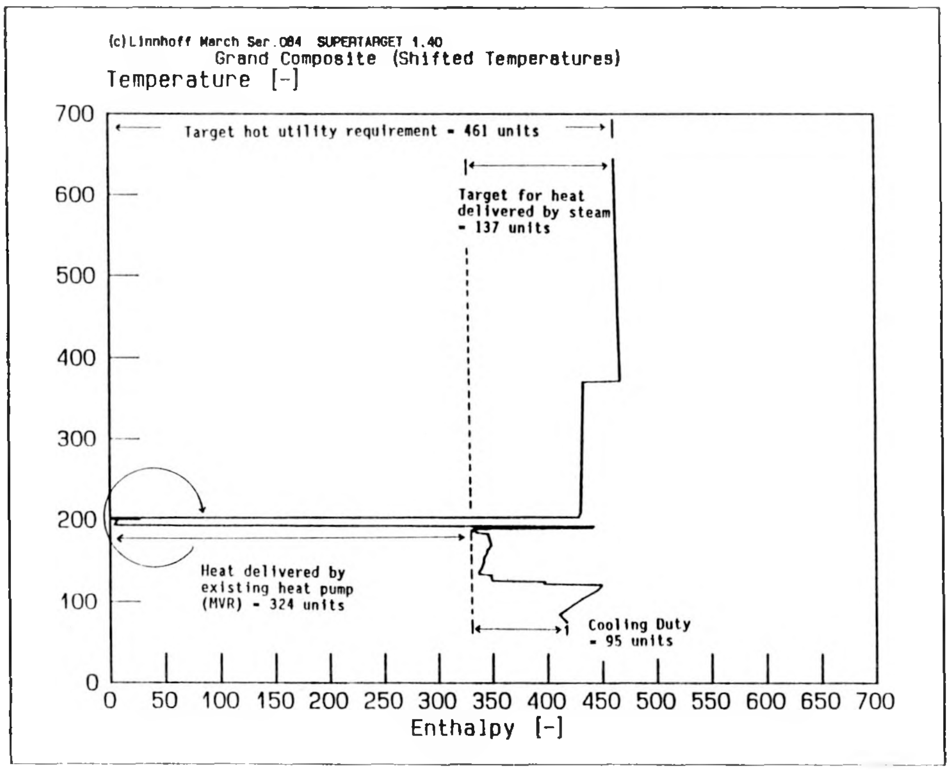


Figure 10a Effect of reduced refinery evaporator first effect temperatures

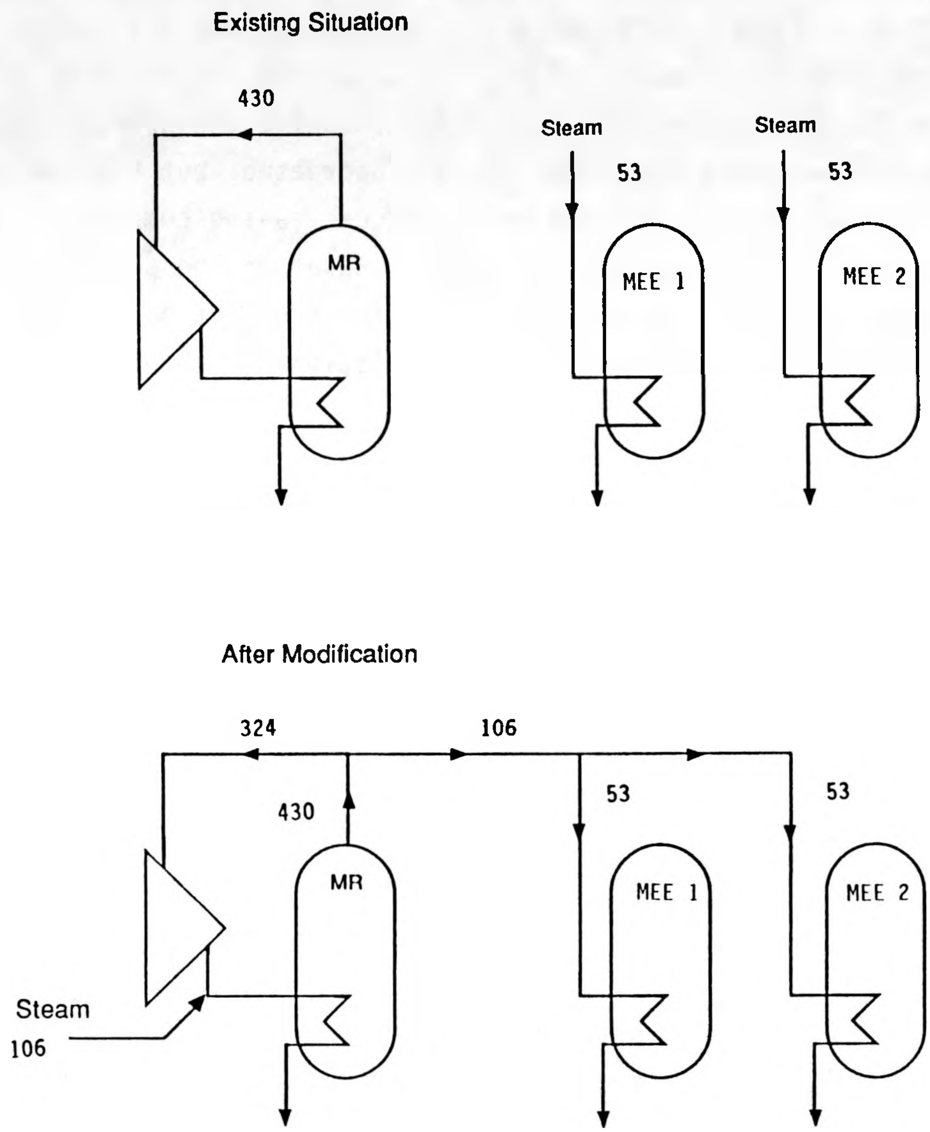


Figure 10b Equipment configuration suggested by Figure 10a

5.1.2 Dextrose Pre-Evaporator (Project 5.2R)

Introduction of a correctly integrated dextrose pre-evaporator could produce results similar to the previous modification. Figure 11a shows the effect of shifting some of the dextrose evaporation duty to a temperature of about 230°F. Now the vapors from the pre-evaporator can be used to drive the process above the pinch. Once again the process steam demand is not decreased, but the evaporation load on the existing dextrose MVR evaporator is reduced saving compressor horsepower and allowing an increase in throughput. Based on the pre-evaporator duty matching the existing multi effect evaporator first effect heat load, the power saving would be worth $106,000/year or the existing MVR throughput could be increased by 25%.

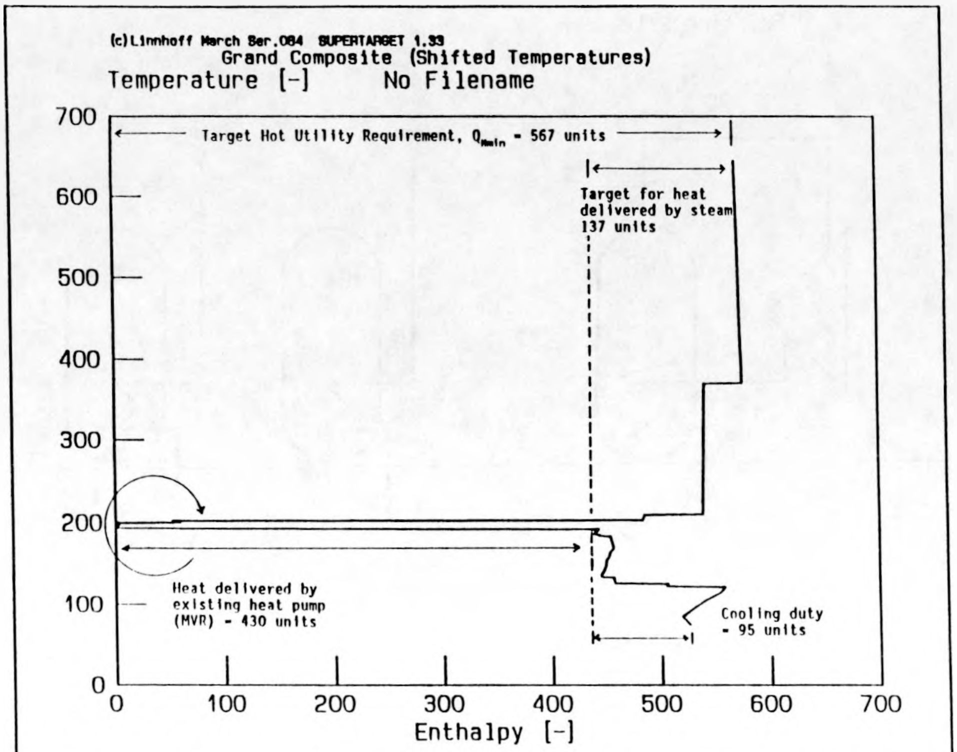
A key factor in this project is the impact of higher temperature evaporation on product quality. However, it is interesting to note that in other manufacturing locations higher temperatures are experienced. This suggests that a higher temperature pre-evaporation scheme is feasible.

5.1.3 Additional Evaporator Effects (Project 5.3R)

The existing multi effect evaporators are inappropriately placed. That is they accept heat above the pinch and reject heat below the pinch. Introducing an additional effect to both units would reduce the amount of 'inappropriately placed' heat transfer and result in reduced energy requirements as shown in Figure 12. Potential savings are worth $189,000/yr. As these evaporators were constructed with space for the additional bodies, the projects could be cost effective.

5.1.4 Operate Process at Higher Solids Content (Project 5.4R)

The majority of the energy usage in the refinery is associated with evaporation. Reducing the evaporation load will cause a corresponding reduction in energy consumption and potentially debottleneck all the evaporators.



Base case refinery grand composite curve

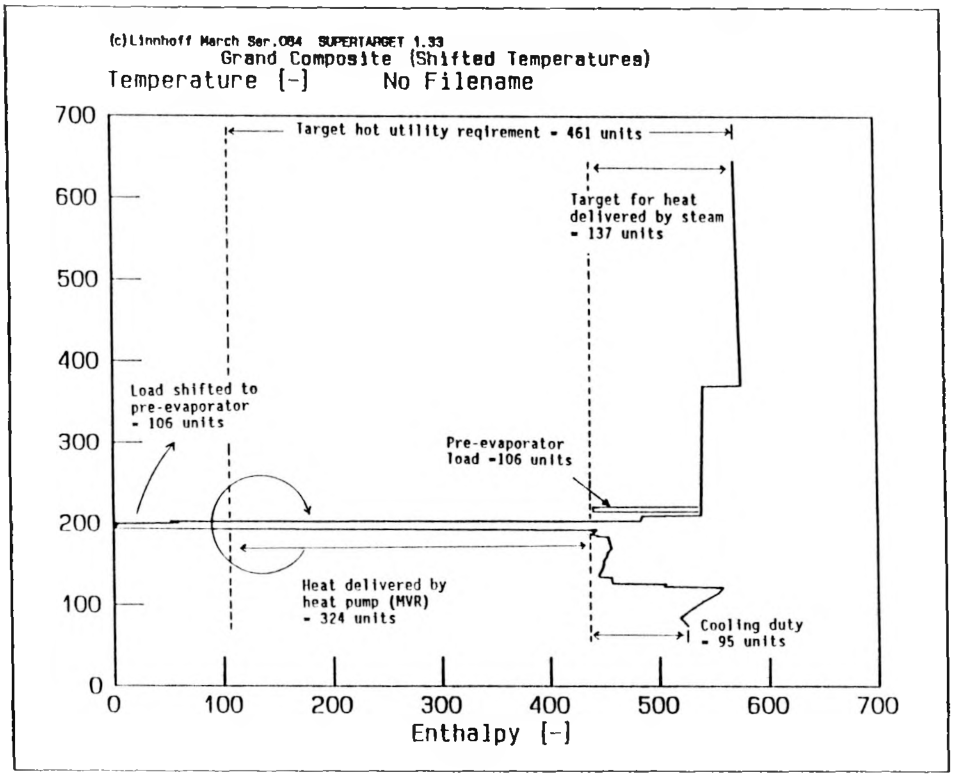


Figure 11a Integration of pre-evaporator in the refinery

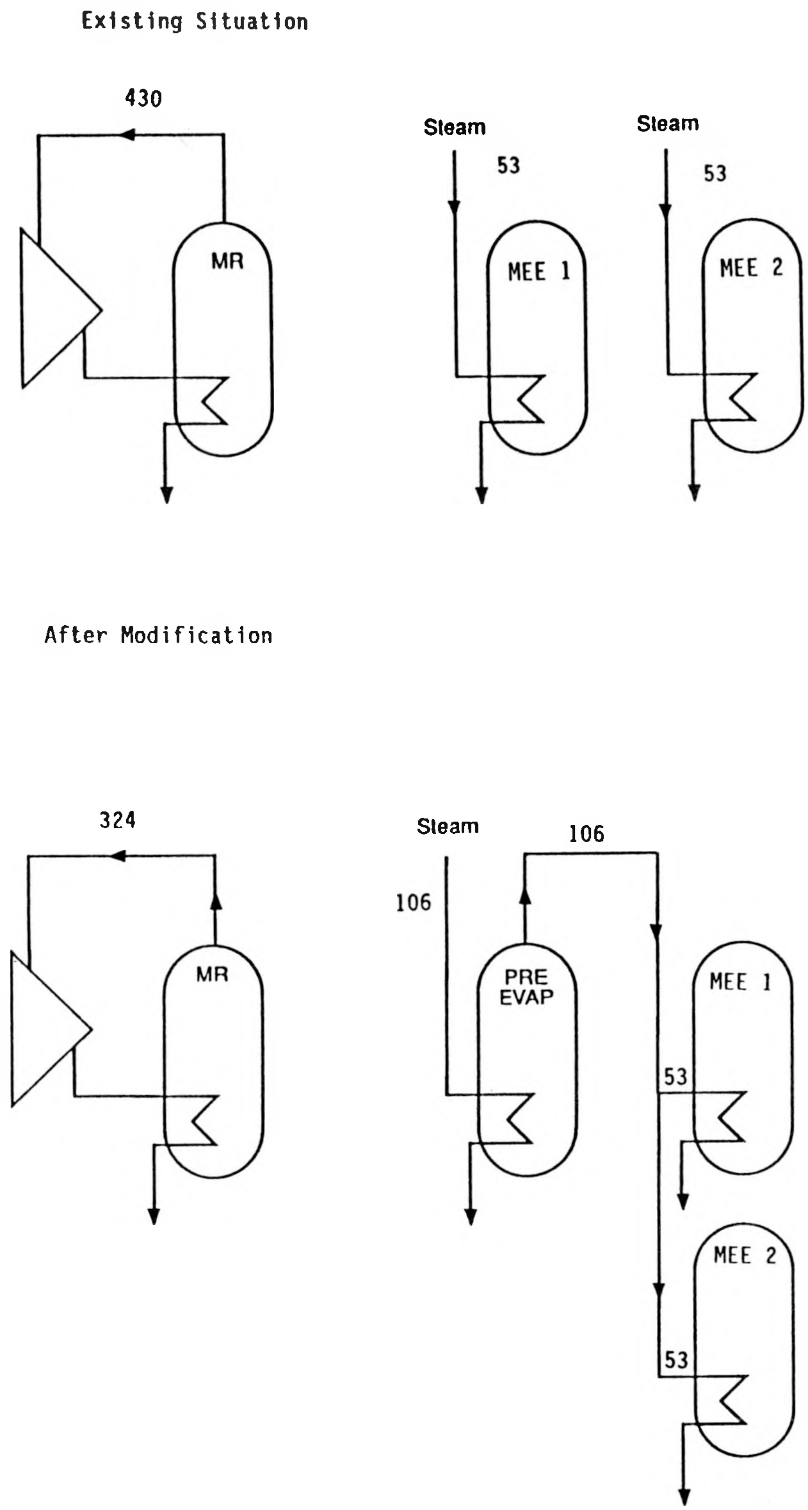
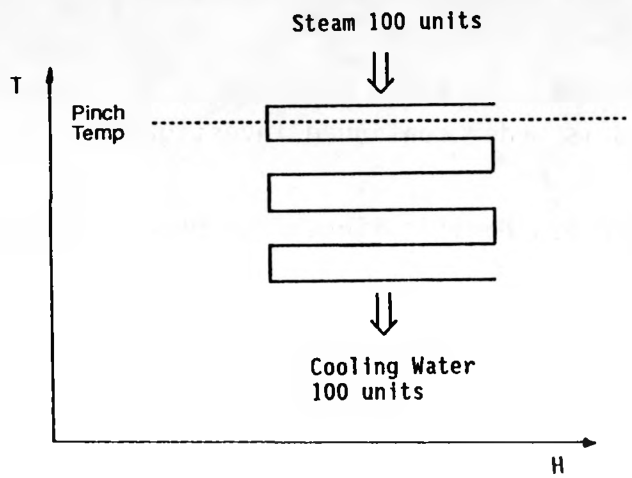


Figure 11b Equipment configuration suggested by Figure 11a

Three effect



Four effect

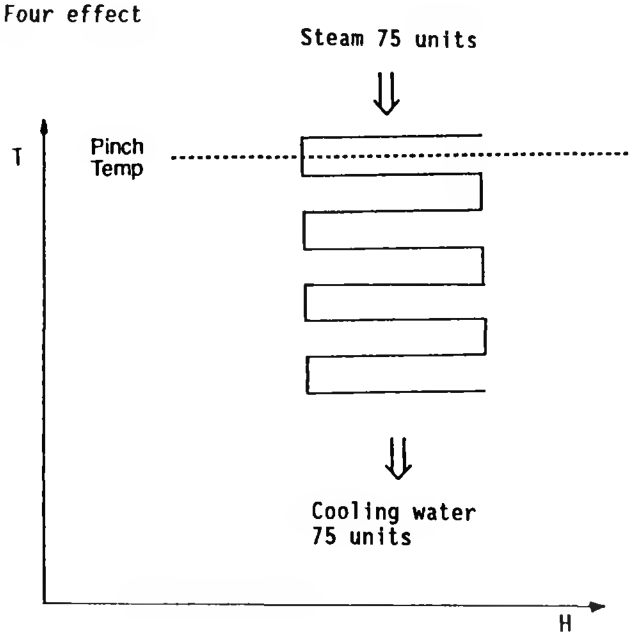


Figure 12 Effect of additional effects on an evaporator

The scope for achieving this is obviously constrained by production concerns, however, possibilities for achieving this include:

- operating saccharification at high solids
- increasing solids content of sweet water
- increasing solids content of raffinate

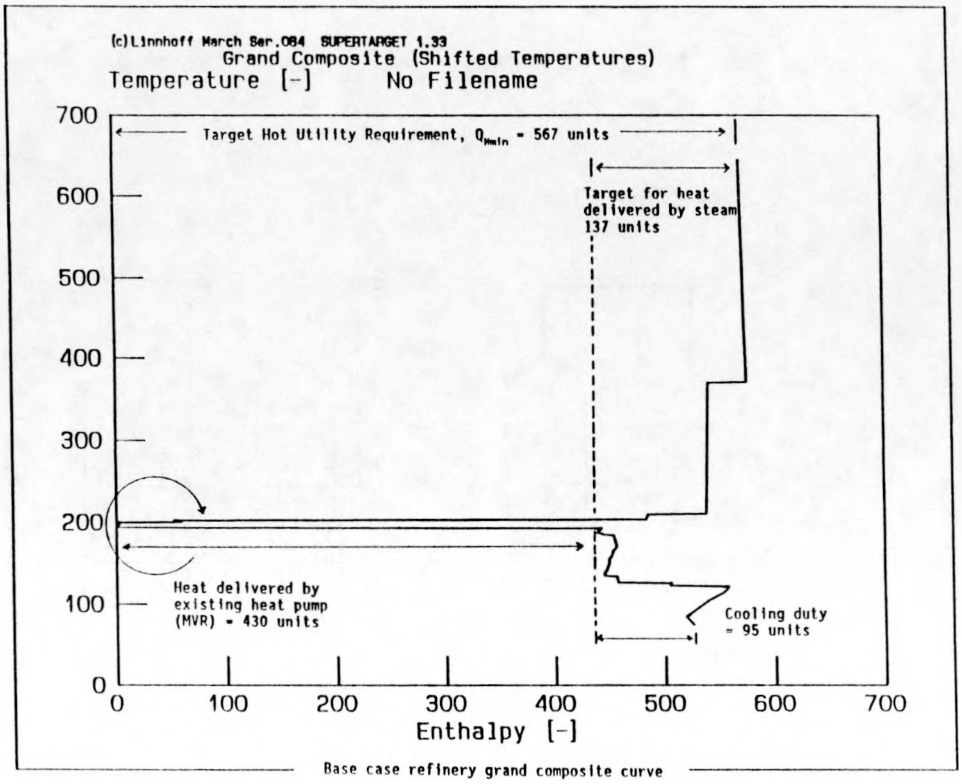
American Fructose staff are aware of these options and the extent to which they can be implemented is under continued investigation.

5.2 Refinery Process Modifications Plus Heat Pumping (Project 5.5R)

Heat pumping and process modifications can be considered in conjunction with each other. One particular combination offers the potential for significant energy savings and debottlenecking of the evaporation system. This scheme involves the use of a pre-evaporator plus thermocompression round the modified first effects of the multi effect evaporators. The effect of this on the refinery Grand Composite Curve is shown in Figure 13a, with the corresponding flowsheet in Figure 13b. The energy saving of $329,000/yr accrues through reduced power input to the existing MVR evaporator and reduced steam consumption in the multi effect units. The estimated capital cost is approximately $1.75 MM resulting in a payback of about 5 years. On energy savings alone, this would not be considered a very attractive project, however, it does allow the refinery evaporator systems to be debottlenecked substantially by the use of only three new evaporator bodies. As four separate streams are being concentrated, this scheme could represent a very cost effective route to capacity expansion while simultaneously achieving energy efficiency improvements.

5.3 Mill Process Modifications (Project 5.1M)

The main opportunity for process modification involves the germ drier exhaust. The germ drier exhaust contains both air and water vapor and has an estimated



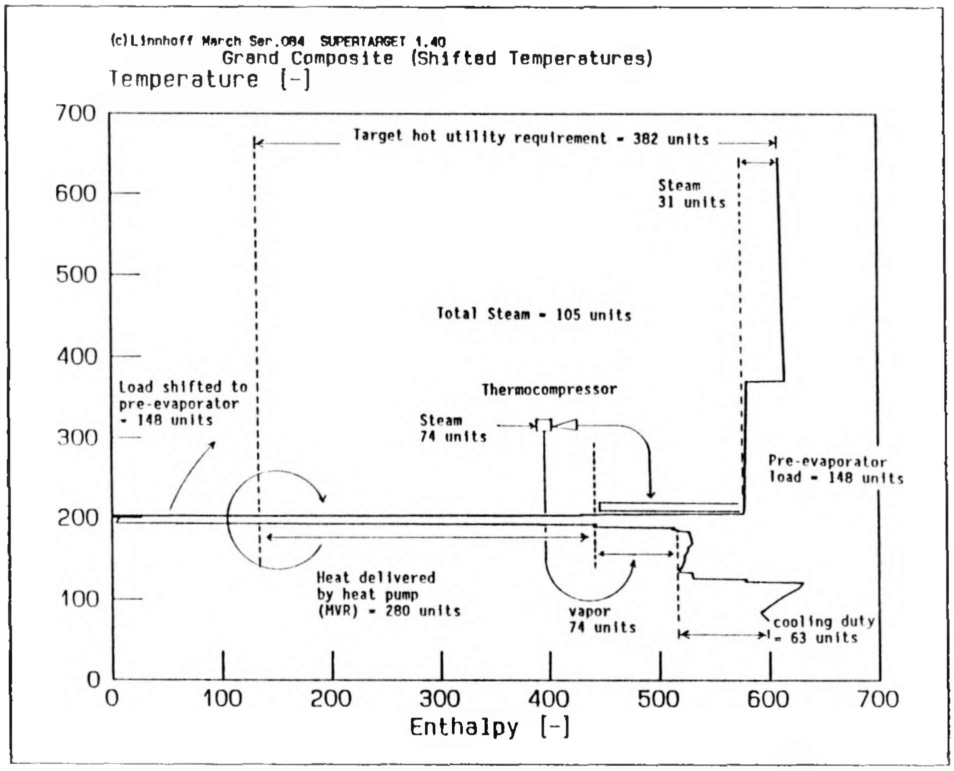
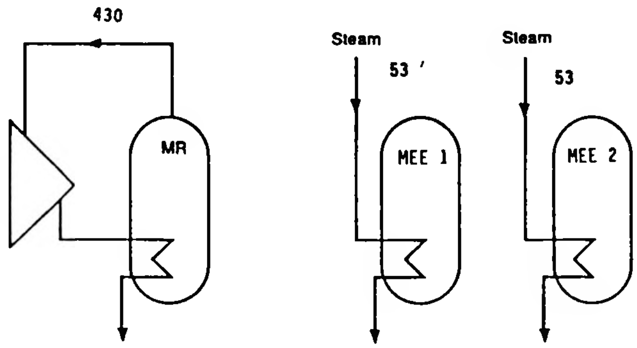


Figure 13a Refinery grand composite curve including shifted loads, pre-evaporation, and thermocompression

Existing Situation



After Modification

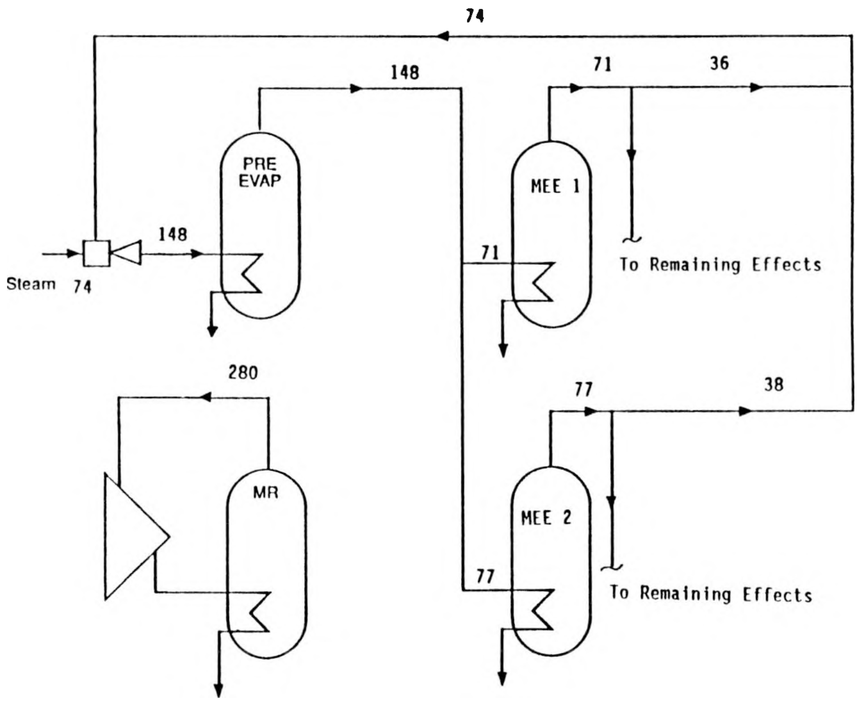


Figure 13b Equipment configuration suggested by Figure 13a

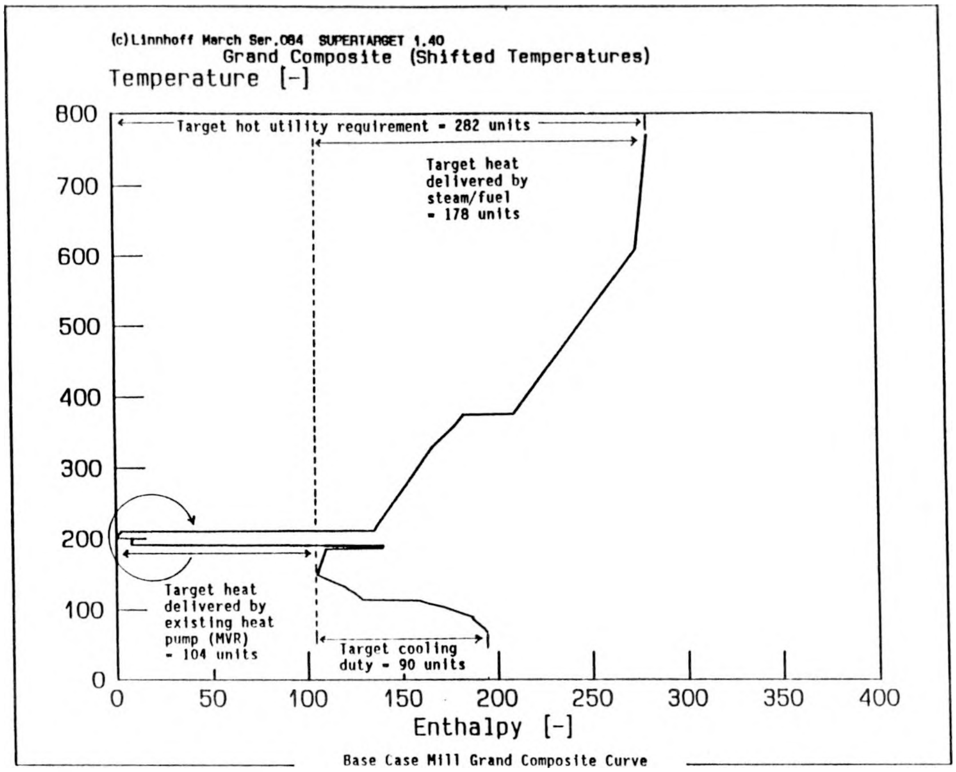
dew point of 160°F. If the dew point could be raised to a high enough level, by reducing the air content, it could be used to drive the steep water multi effect evaporator. This has been successfully implemented in other corn processing locations. The grand composite curve for this revised situation is compared to the base case in Figure 14.

Overall the hot utility target is not decreased, but now the appropriate amount of heat pumping possible has increased. Because heat supplied by the existing heat pump (MVR) is less expensive than heat supplied by steam, this modification introduces an additional scope to save $110,000/year over the base case.

5.4 Mill Process Modifications Plus Heat Pumping (Project 5.2M)

Currently the steep water evaporation duty is split between an MVR and a multi effect evaporator, with the MVR unit picking up most of the duty. Because the multi effect unit is operating at low load, the effects are over surfaced resulting in a low temperature in the first effect steam chest. This opens up the opportunity for integration between the MVR Unit and the multi effect unit.

A combination of switching load between the multiple effect and MVR evaporators plus thermocompression also offers savings. In this case, the evaporation load in the multi effect unit is increased and that in the MVR reduced. The resulting grand composite is shown in Figure 15a. This scheme eliminates the need for the MVR compressor but increases the steam demand. Annual savings amount to $82,400/year. Figure 15b shows the flowsheet for this scheme.



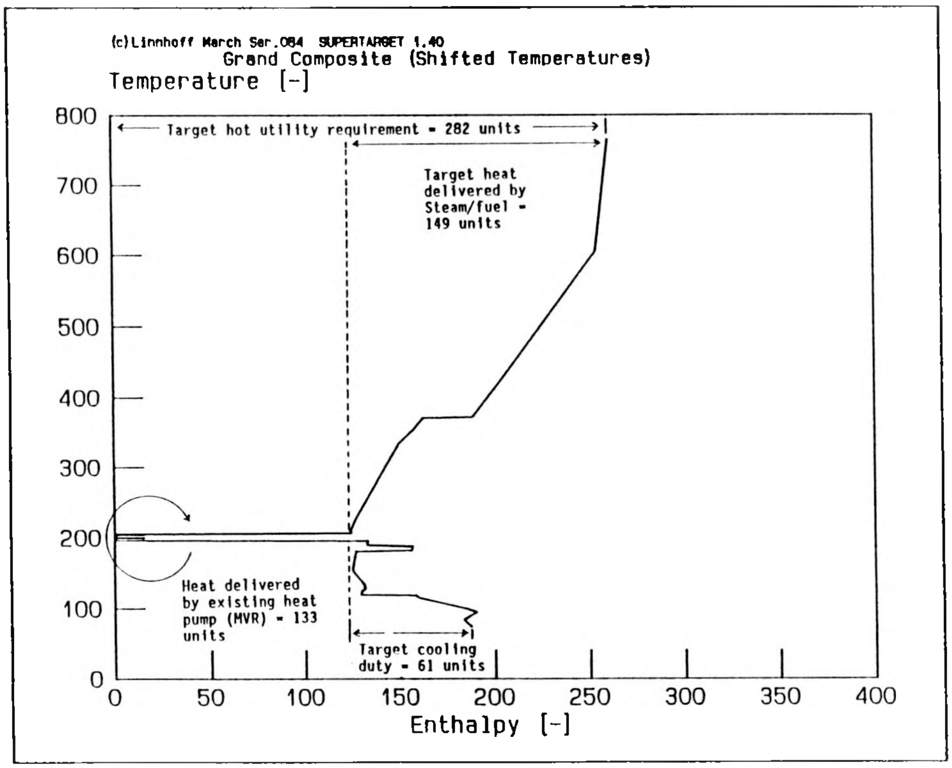
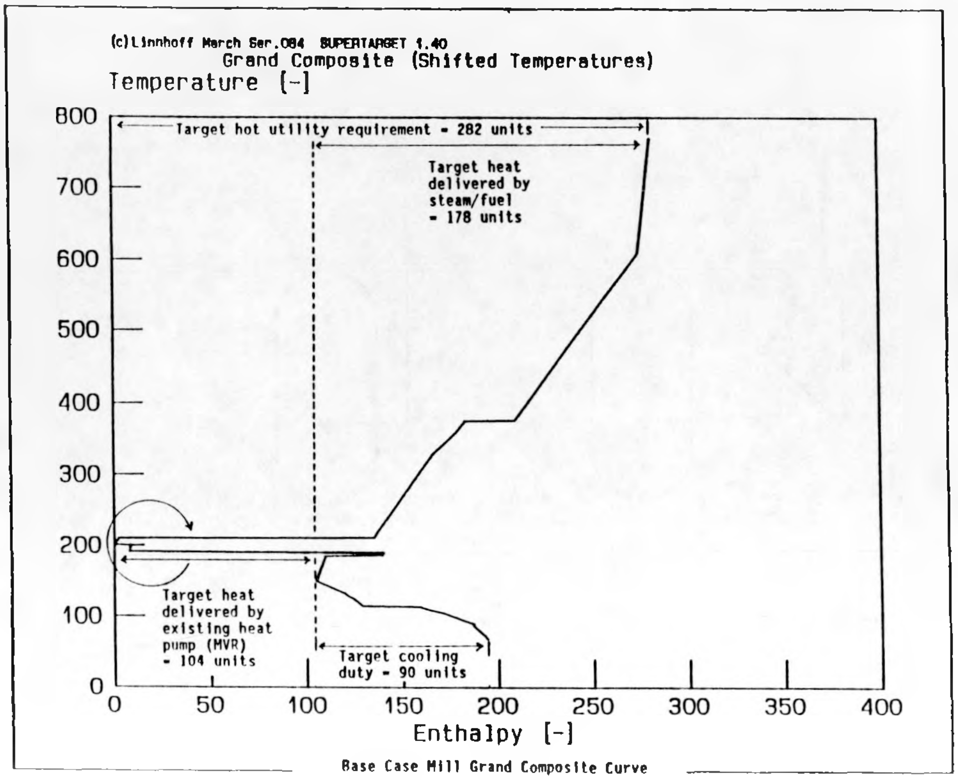


Figure 14 Mill Grand Composite Curve Including Modified Germ Dryer Exhaust



Base Case Mill Grand Composite Curve

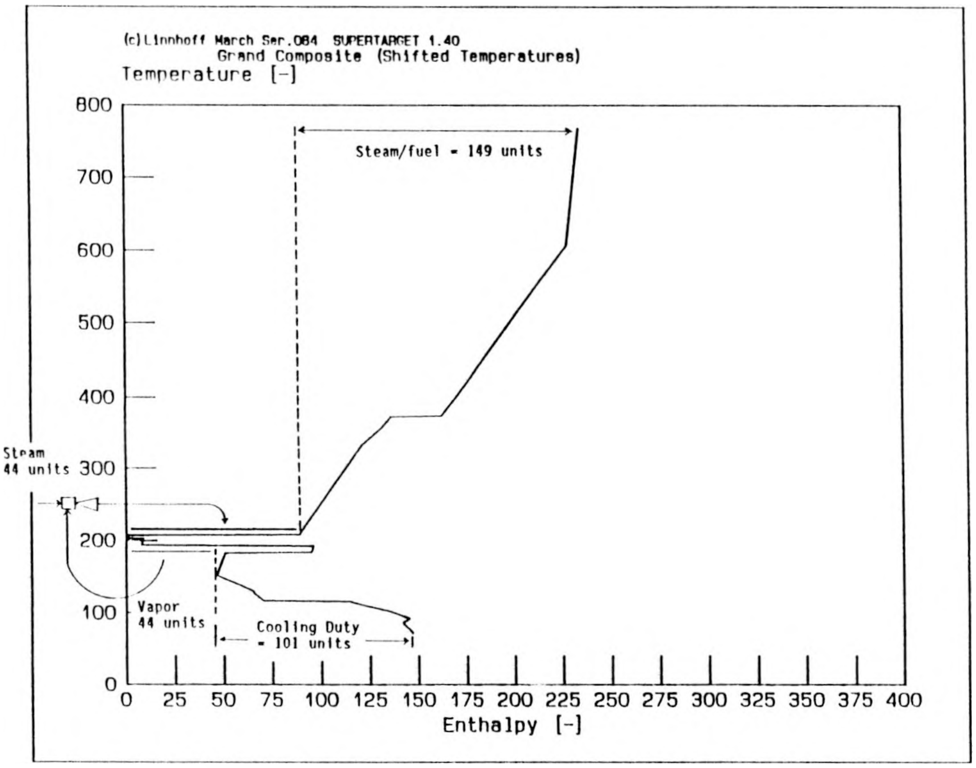
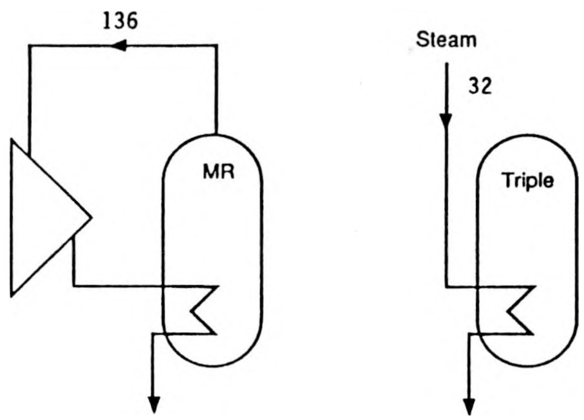


Figure 15a Mill Grand Composite Curve Including Swapped Evaporation Loads and Thermocompression

Existing Situation



After Modification

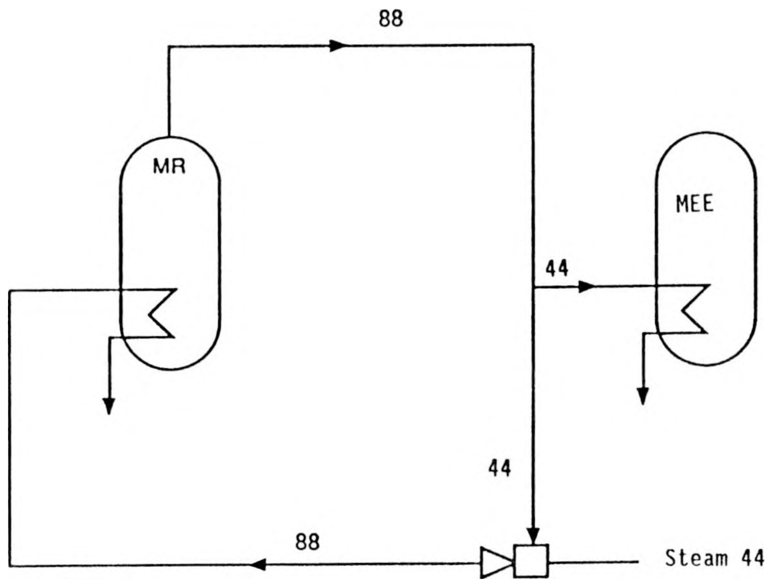


Figure 15b Equipment configuration suggested by Figure 15a

6.0 UTILITY SYSTEM DESIGN

Having established what the minimum process energy requirements are, the various utility systems that can satisfy those requirements can be investigated. The grand composite curve for the refinery plus mill is used for this purpose. Figures 16a shows the grand composite curve for the existing utility mix. Figures 16b and c show other possible utility systems, which are:

6.1V) Use of heat pump (MR units), 15# and 150# steam generated by expanding 650# steam through a turbine to generate power, and gas.

6.2V) Use of heat pump (MR units), 15# and 150# steam generated by expanding 450# steam through a turbine to generate power, and a gas turbine engine also generating power.

6.3V) Expand 150# steam through a turbine to supply 15# steam for the multi effect evaporators.

For Project 6.1V to be implemented, the existing coal boiler would have to be modified to operate at the higher pressure. This modification is possible and was recently examined as part of a cogeneration feasibility study. This study proposed to raise high pressure (600#, 750°F) steam and expand it through a turbine to 150# and 25# generating power. In addition, a new LP steam distribution system would be required. Based on the existing site steam demands, the annual cost saving would be $800,000/year with an estimated capital cost of $4MM, resulting in a simple payback of 5 years. Implementing the steam saving measures outlined in Section 3.0 will reduce net savings to $550,000/yr, increasing the payback to 7 years.

Implementation of Project 6.2V requires hot air for the direct contact driers in the mill to be supplied by a gas turbine exhaust stream, as shown in Figure 17. The annual cost saving would be about $800,000/year, with an estimated capital cost of $3.5MM resulting in a payback of 6.4 years.

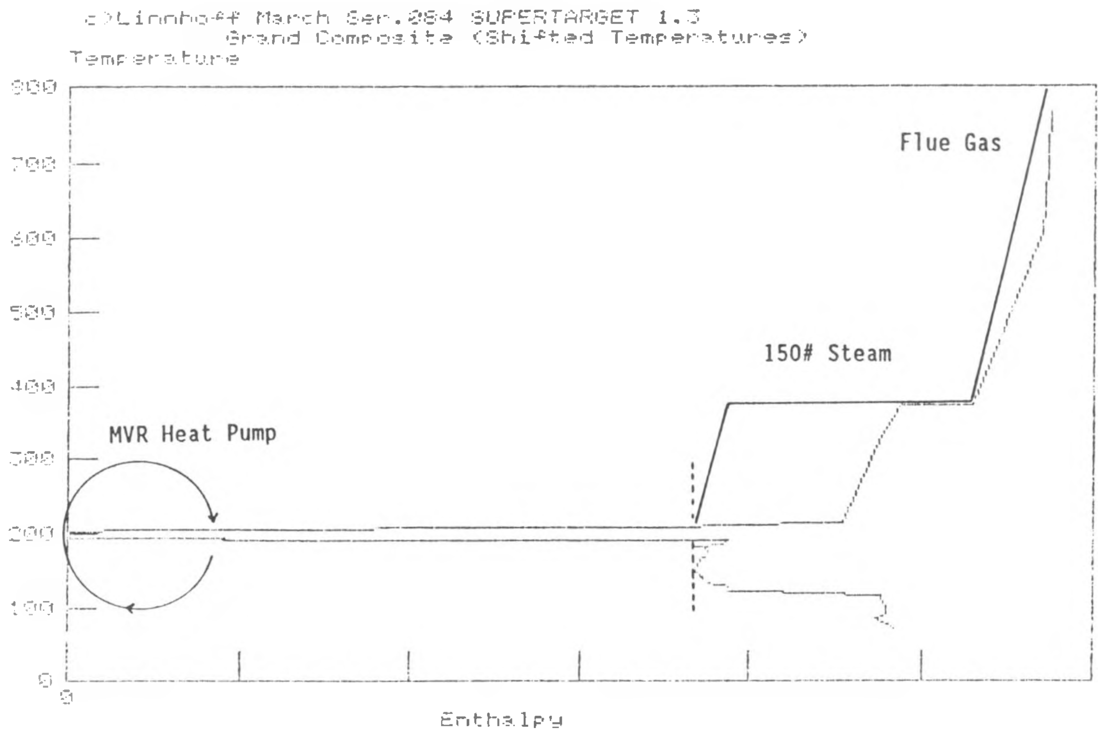


Figure 16a Utility System Option 1

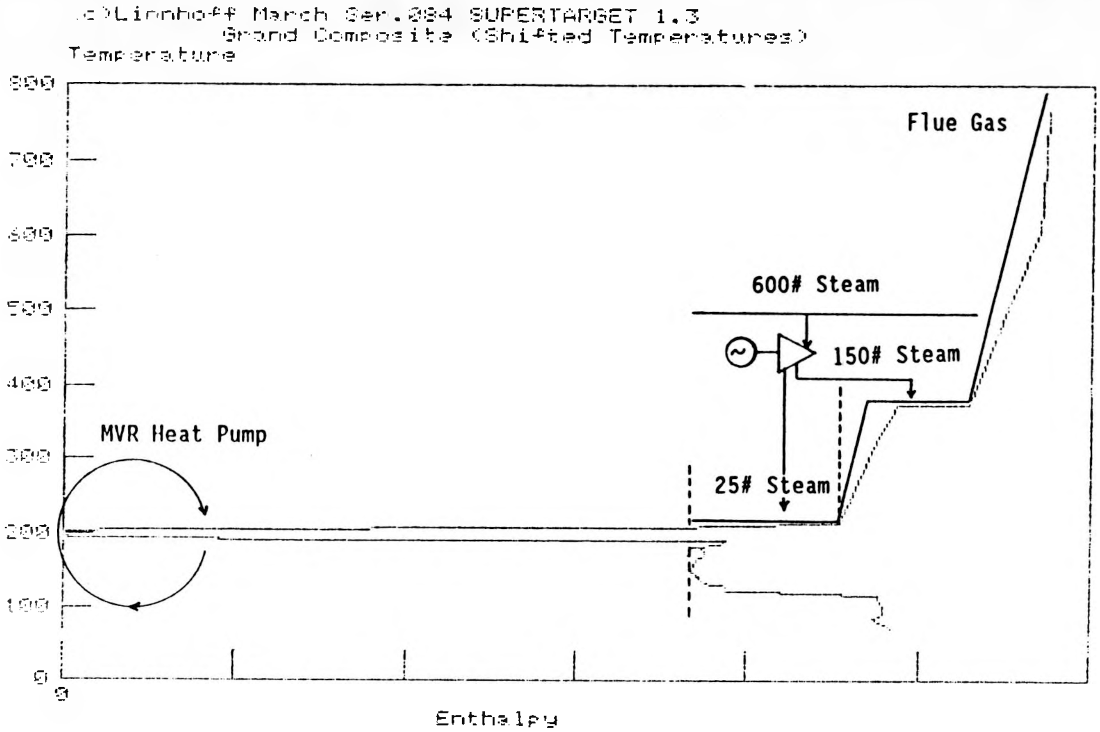


Figure 16b Utility System Option 2

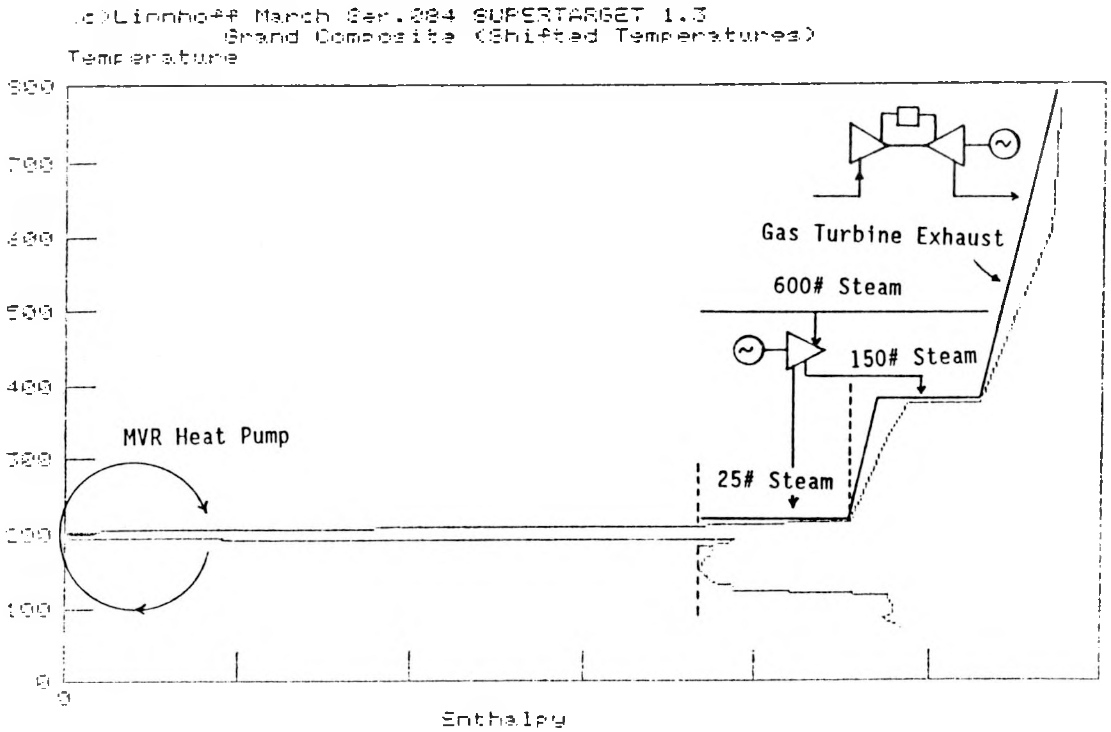


Figure 16c Utility System Option 3

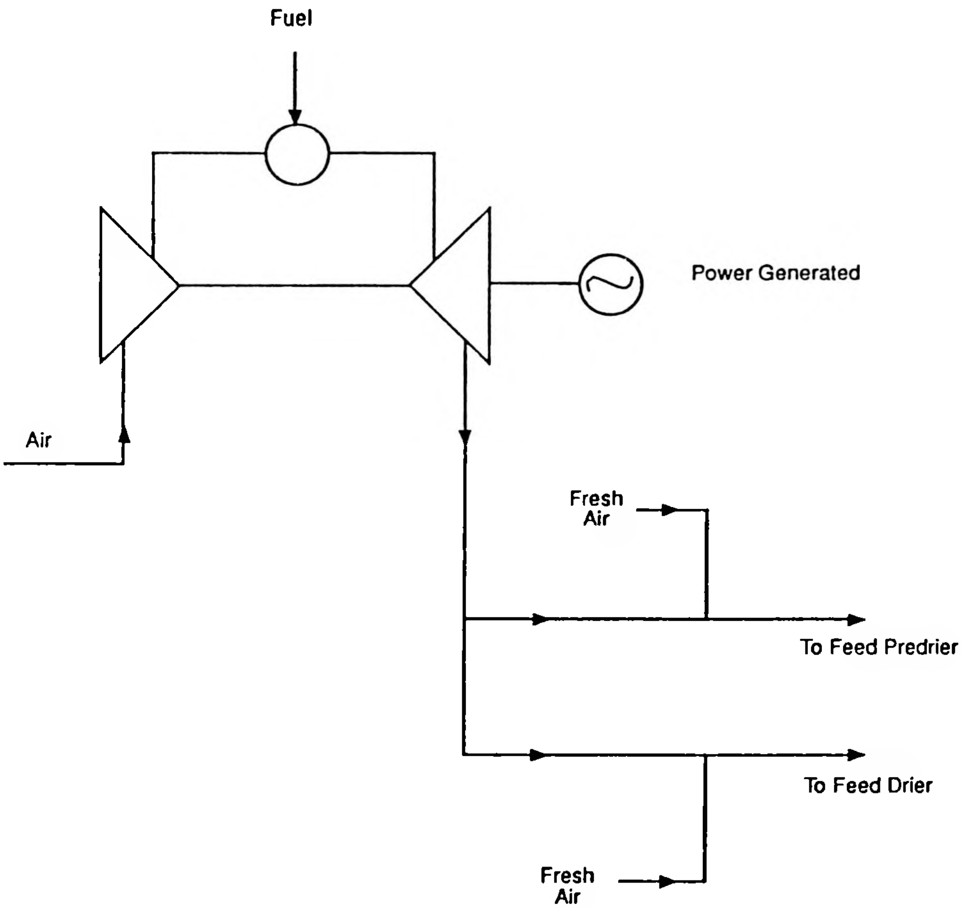


Figure 17   Gas turbine integration with driers

An additional opportunity arises Project 6.3V because currently 150# steam is expanded to 15# to drive the multi-effect evaporators. If this expansion were done through a turbine, power worth $157,000/year can be generated. The estimated capital cost is $345,000 resulting in a simple payback of 2 years. Clearly, the choice of utility system influences the viability of process modifications and other heat recovery projects. Thus, it is important to know what other opportunities exist and how they all interact.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Table 7.1 summarizes the potential projects identified in this study. All entries are made for these projects deemed most feasible. Blanks indicate numbers which were omitted on projects less feasible.

Additional heat recovery offers the most attractive energy cost reduction strategy for the HFCS process. Savings of around $800,000/year (about 10% of total fuel and power bill) can be achieved at an overall payback of 15 months.

The process studied already makes use of heat pumping in the form of MVR evaporators. These evaporators are substantially correctly integrated with the process. However, additional opportunities for utilizing heat pumps exist. One scheme in particular (Project 5.5R) incorporating a thermocompressor heat pump and a modified evaporation sequence could result in energy savings of $329,000/year. Although this project only has a payback of 5 years based on energy savings alone it's main attraction is significant debottlenecking of the refinery evaporation system with a minimum of new equipment items.

Several cogeneration opportunities were identified; however, despite potentially large savings of $1.6 MM/year, the paybacks were in the 5 year range. One small simple scheme could produce savings of $157,000/year at a 2 year payback.

The recommended implementation sequence would be to first install the heat recovery projects. If debottlenecking of the plant is required, then the heat pump project described above should be implemented. Finally, cogeneration, based on the modified heat loads, can be considered.

It is felt that the results of this study will be applicable to plants incorporating refinery sections throughout the wet corn milling industry. The results of this study are in line with previous experience indicating that thermal loads can be reduced by 15-25%. Also, integration/modification of evaporation systems may be applicable to other evaporation intensive industries.

Table 7-1 Project Summary

Project Category	Project #	Utility Reductions Steam/ Fuel units/h	Utility Reductions CW units/h	Change in MVR Power Input (1) units/h	Power Generated (2) units/h	Saving $000's/yr	Capital Cost $000	Pay Back years
Additional heat recovery between process streams	3.0 R	72	71	0	N/A	442.5	450	1
	3.0 M	41	9	-4	N/A	395	606	1.5
Heat pumping projects	4.1 R	-	-	-14.5	N/A	106	-	-
	4.2 R	79	87	+31	N/A	381	1700	4.5
	4.3 R	32	32	-	N/A	189	510	2.7
	4.1 M	-	-	-4	N/A	37	-	-
Process Modification and and Process Modification plus Heat Pumping	5.1 R	-	-	-14.5	N/A	106	-	-
	5.2 R	-	-	-14.5	N/A	106	-	-
	5.3 R	32	32	-	N/A	189		
	5.4 R	-	-	-	N/A	-	-	-
	5.5 R	32	32	-19	N/A	329	1750	5
	5.1 M	29	-	+4	N/A	110	_	_
	5.2 M	<15>		-17	N/A	82.4	_	_
Utility system Projects	6.1 U	N/A	N/A	N/A	7.3	800	4000	5
	6.2 U	N/A	N/A	N/A	64	800	3500	4.4
	6.3 U	N/A	N/A	N/A	61.5	157	345	2

NOTE: (1) Baseline power for refinery MVR = 58 units
Baseline power for mill MVR = 18 units

(2) Power output converted to heat units and related to existing site heat demand of 1000 units

Existing site power demand on this basis = 160 units